THE UNIVERSITY OF ALBERTA

INHERITANCE AND INTERRELATIONS OF LIVE PERFORMANCE AND CARCASS CHARACTERISTICS IN BEEF CATTLE

A THESIS

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Inheritance and Interrelations of Live Performance and Carcass Characteristics in Beef Cattle" submitted by Robert Bertram Church, B. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

An investigation was undertaken to evaluate live performance, carcass characteristics and meat quality traits of 183 progeny test steers sired by 10 Hereford, 3 Charolais, 1 Holstein and 1 Angus sires and from grade Hereford dams. An additional group of 10 steers were Hereford sired, from Holstein X Hereford dams.

Disproportionate data necessitated an analysis of variance using a nested or hierarchial classification. Components of variance were estimated for groups (feeding method, ranch and breed), sires within groups and progeny within sires. Heritabilities were calculated from paternal half sib correlations. Intercorrelations among 42 performance and carcass traits were calculated.

Sire variance and heritability estimates were high for feedlot average daily gain (ADG) for the calves which were fed to market condition rapidly (fed-calf program) but were low for those carried on a lower plane of nutrition for 174 days followed by full feeding to market condition (fed-yearling program). High heritabilities were obtained for lifetime average daily gain (LADG) under both programs and would therefore seem to be a more useful measure of gainability than feedlot ADG.

Dressing per cent and per cent kidney fat showed significant sire differences with heritability estimates of 78 per cent and 45 per cent respectively. Measures of fat cover over the rib-eye had low heritabilities which were probably influenced by marketing at an appraised constant finish. Fat cover per cwt. had a higher heritability at 46 per cent and would therefore be a preferred measure for progeny testing purposes.

With a heritability of 89 per cent, rib-eye area per cwt. was superior to rib-eye area, rib-eye depth and per cent separable lean in a rib core, for detecting sire progeny differences in leanness. Rib-eye depth proved to be of no value in this regard.

No significant group or sire within group differences were obtained for retail yield although the heritability estimate was 29 per cent for this trait. Marketing at an appraised constant finish may have masked sire differences for this measure.

Sire progeny groups did not differ in ether extract of _longissimus dorsi_ muscle, a measure of marbling. Sire progeny group differences were easily detected for tenderness of the _longissimus dorsi_ muscle. A similar result was obtained for muscle fiber diameter.

Average fat cover was the best individual predictor of retail yield accounting for 29 per cent of its variation. Estimating yield by the U.S.D.A. formula of Murphey _et al_. (1960) was no more accurate as a predictor than fat cover alone. Other possible predictors of retail yield along with their coefficients of determination were; per cent trimmed chuck (17 per cent), per cent trimmed round (15 per cent), per cent separable lean in a rib core (11 per cent) and rib-eye area per cwt. (6 per cent). No significant relationships were found between measures of gain and retail yield or measures of quality and retail yield.

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INTRODUCTION

The necessity of improving beef cattle populations to produce a greater amount of muscle per unit of daily gain in live weight and to maintain the present eating desirability of beef is receiving a great deal of attention in animal breeding research.

To start the long process of beef production which terminates on the consumer's plate one should go back to the producer of beef cattle and examine his criteria of top market cattle. Breeders of necessity, get their information from the market requirements as reflected in the sale value of their cattle. Market value is based on the expected carcass grade, as presently defined in the Grade Standards, and dressing percentage. The producer, therefore, has a genuine interest in the adequacy of the Grades for reflecting real value differences.

Recently there has been an increase in consumer aversion to excess fat on retail beef cuts. The retailer has been forced to trim an increasingly greater amount of fat from carcasses to market a product acceptable to the consumer. Wide variations in cutability yields among carcasses of the same grade have been shown. Value differences associated with cutability variation should be passed on as financial incentives to producers to make cutability a worthwhile selection criterion in any progeny or performance testing program. Ideally the best way of evaluating a carcass is by actual retail cutout but this is difficult to standardize, costly and laborious. Research workers have been looking for less costly methods of carcass evaluation utilizing both live and carcass measures as predictors of carcass value.

For many years animal breeders have been aware of sire and breed differences in performance and carcass characteristics but only recently have producers become interested in sire differences, primarily for performance traits. With the advent of artificial insemination (A.I.) it has

become increasingly more important to identify superior performing sires because of the number of offspring left by any particular bull. Animal breeders are also interested in the relationship of performance and measures of carcass value to determine if direct selection for each characteristic is required for improvement of both traits.

The study reported herein was undertaken specifically to evaluate inherited differences in live performance and carcass characteristics and to assess the interrelations of these live and carcass characteristics in an attempt to determine useful predictors of retail yield. Another object was to attempt to estimate the minimum numbers of progeny needed per sire for the most efficient and meaningful progeny test.

REVIEW OF THE LITERATURE

The question of type or conformation in beef cattle has been one of controversy for many years. The trend up until the early 1950's was toward the development of more compact, short-legged types of beef cattle within the British breeds. Objective information is not available on the extent of these changes but most observers feel that breeders of beef cattle have developed much smoother types that finish at lighter weights. Lush (1932) states "steers of many types will gain well and steers which gain the same way may be of many different shapes. The same is true of dressing per cent and meat values, although future dressing per cent and future live meat values are slightly more closely correlated with conformation than future gain is".. Beef cattle breeders took such statements to mean conformation was highly correlated with the retail yield of a steer.

In the past carcass grade and conformation have been utilized as standards in carcass evaluation by research workers in animal breeding and meat characteristics. Recently with the shift in retailing meat due to the chain store self service counter and the increasing aversion to fat of the consumer,

salable retail yield has been used as the evaluation criteria by both groups. Beef cuts in a self service counter must be uniform in size and appearance. The retailer trims excess fat from the cut to satisfy the consumer who demands quality beef without excess fat. Some workers have recognized the change in conditions and have proceeded to investigate assumed associations of carcass traits with retail yield.

The first separation of the carcass into lean, fat and bone was done in 1919 by Trowbridge *et al.*, but this work was neglected for many years. Not until Hankins and Ellis (1939) first used the concept of prediction equations for separable lean was the original work considered. Current research, since about 1959, is attempting to objectively define and accurately predict both the quantitative and qualitative aspects of beef carcasses.

I. Progeny and Performance Testing of Beef Cattle

The measurement of a sire's worth by evaluating his progeny is not a recent tool but one used by Robert Bakewell in his exploratory sire leasing practices. He used superior animals, once identified in lease

herds, in his own herd. Most of our present beef breeds were developed with the use of sires evaluated on the basis of their progeny.

Progeny testing in one form or another is basic to all genetic studies and probably owes its original role in Genetics to Mendel. Progeny testing on a broader scale in livestock was introduced in Denmark for swine (Lush, 1936) and later for dairy cattle (Johansson, 1954). Research workers in the field of animal breeding became aware of the possible differences between beef sires, after reports to this effect became available from the Miles City Range Experimental Station (Clark et al., 1943; Knapp et al., 1942; Knapp and Clark, 1950). Differences were reported for all economic performance traits as well as carcass traits. Progeny testing was a major tool in the formation of the Line I Hereford which was developed at the Miles City Station (Knapp et al., 1951). Bulls were selected for the herd on the basis of the performance of their steer progeny (Knapp et al., 1942). The effectiveness of progeny testing depends on the heritability of the trait selected for and the number of offspring used to test a sire (Berg, 1955).

In the last decade programs using various forms of performance testing for beef cattle have been introduced Federally and Provincially across most of Canada. Performance testing programs have been expanded recently to include progeny testing of potential sires put into service by Artificial Insemination Centers. The function of the progeny test program is to provide breeders with information which will aid in identifying superior performing sires (Baird, 1962).

Performance testing of individual bull calves is the first step in the process of selecting superior performing potential sires. The bulls which have proven to be superior in performance are then progeny tested to reveal the heritability of the various factors being considered in

performance and carcass quality. The most efficient progeny testing should be done on the basis of contemporary comparisons. Artificial insemination is a means of facilitating progeny testing by contemporary comparisons over a wide range of herd conditions and facilitates continuity of breeding and selection programs.

Knapp and Nordskog (1946), using data from the Miles City Station presented the first estimates of heritability of quantitative traits in beef cattle. They reported low (0.28) estimates for birth weights but high estimates (0.86) for final weights. Heritabilities were above 50 per cent: for weaning conformation score, 0.64; slaughter steer grade, 0.81; carcass grade, 0.84; and area of rib-eye muscle, 0.69. Several of the heritability estimates were very high and a bias was suggested owing to small numbers and environmental effects. Since that time numerous studies have been made as summarized by Warwick (1958) and Shelby *et al.* (1963). Studies involving rate of gain indicate heritability to be about 40 per cent (Knapp and Clark, 1950; Shelby *et al.*, 1963).

Guilbert and Gregory (1944) point out that the relationship between rate of gain and efficiency must take into consideration the composition of carcass produced. Heritabilities of carcass traits can be summarized as follows; dressing percent, 0.73 (Shelby *et al.*, 1955); carcass grade, 0.30 to 0.84 (Knapp and Nordskog 1946; Rollins *et al.*, 1962); rib-eye area, 0.69 (Knapp and Nordskog, 1946); and tenderness, 0.80 and 0.67 (Cartwright *et al.*, 1957; Palmer, 1961). Sire differences complicate heritability estimates in many experiments (Brinks *et al.*, 1962). Magee *et al.* (1958) reported heritability estimates of near 0.1 for area of rib-eye, the differences between the same sire groups each year however were statistically significant in only one year. If only a few comparable sires were used each year, one should not expect to find a significant

difference between means of sire groups in only one year.

II. Carcass Composition

The result of growth in a beef animal is really a change in the proportions of muscle, fat and bone. The composition of each of these tissue types changes as an animal matures. Genetic factors are expressed in growth in a number of ways and these indirectly affect meat quality (Lowe and Kastelic, 1961). Some animals grow faster and fatten quicker as Callow (1947) has pointed out. Changes in tissues which occur in animals during growth are a function of heredity, nutrition and environment (Callow, 1962).

Muscle tissue performs work by contraction or by shortening and thickening. Each muscle is constituted to best perform its function. There are two types of muscle, smooth and striated. Smooth muscle is usually involuntary and found in the internal organs. Striated muscle, with the exception of cardiac muscle, is voluntary and attached to the skeleton. Striated muscles are referred to as "meat" or "lean" in the slaughtered, dressed carcass.

Basically, all striated muscles are made up of primary muscle fiber bundles held together by connective tissue. Several primary muscle bundles in turn are bound by connective tissue to form secondary bundles. This continues until a muscle is built up (Hirzel, 1939). Each muscle bundle is made up of a very large number of parallel independent muscle fibers held together by interstitial connective tissue or endomysium. Endomysium is a thin layer of collagenous tissue which may or may not also contain elastic fibers.

Muscle fibers in cross section are round or oval, and vary in diameter and length. Except for those fibers attached to a tendon, which are

blunt, they tend to taper to a point. Surrounding each muscle fiber is a continuous, thin, transparent, structureless membrane, the sarcolema. A freshly separated muscle fiber appears slightly yellow and striated in both longitudinal and transverse directions. Striations are due to the arrangement and optical properties of the myofibrils which are numerous very thin fibrils located in the sarcoplasm of each muscle fiber. These thin fibrils lie parallel to one another and run the entire length of the fiber, accounting for longitudinal striation. As muscle tissue develops there is an increase in muscle fiber size but no increase in fiber numbers (Joubert, 1956). Each muscle fiber contains numerous nuclei, generally located just beneath the sarcolema. The sarcoplasm consists of myosin and myogen, nucleoproteins, metabolic intermediates, enzymes, salts and a pigment myoglobin (Hiner et al., 1953).

The amount of bone in beef cattle has long been a controversial issue among cattlemen. Breeding cattle are criticized for being too light of bone and slaughter steers' quality indicated by refinement of bone. Ever since Hammond (1932) showed a positive correlation between weight of muscle tissue and weight of bone in an animal, research has been done on the ratio of the two tissue types. Usually a correlation of about 0.75 is obtained between separable bone and lean (Callow, 1948; Hankins et al., 1943; McMeekan, 1941; Wythe et al., 1961) indicating the desirability of heavy boned steers. Packers on the other hand prefer a lighter bone as it is believed associated with higher yield (McMeekan, 1956).

Inheritance fundamentally determines the potential development of both bone and muscle characteristics (Wythe et al., 1961). Hankins et al. (1943) found muscle-bone ratio to be definitely inherited in beef and dual purpose cattle. Callow (1948) found that the ratio of lean to bone remained constant at 4:1 during the first three years of an animal's growth, until

18 to 20 per cent fatty tissue was reached, after which the ratio of bone decreased as fatty tissue increased. Callow (1961) showed an inverse relationship between fatty and muscular tissue, about one third of the weight of a slaughter animal being muscle. Fresian steers in comparison to the British beef breeds showed the highest percentage muscle and bone tissue. Orme et al. (1959a) reported that the percentage primal cuts was related to the weight of the cannon bones. Callow (1962) reported that the average percentage of fat in a muscle is not constant, nor are muscles alike in their distribution of fat. The average percentage of fat varies in a muscle depending on how early the muscle reached mature size in relation to growth of the animal. Fat is laid down more slowly in early developing tissues such as the chuck and fastest in late developing areas such as the loin (Callow, 1962). Increasing body fatness is a stress that may increase muscle mass which in turn puts a stress upon bone causing its increase (Pitts, 1962).

Callow (1949) showed that for rapid fattening, the same level of fatness is reached at a lower carcass weight than is the case with slower fattening. Rapid fattening can be expected, for the same level of fatness, to produce carcasses with a slightly smaller percentage of bone than when fattened more slowly (Callow, 1949). No comparable data is available for the effect of rapid fattening on lean content but one would expect less lean because of the ratio between lean and bone.

The distribution of fat deposits in an animal has implications which are not readily apparent. The distribution of fat internally or externally on the carcass is of importance in relation to dressing per cent and cutability. The external fat is of value to palatability and has a major effect on the retail yield of a carcass. Internal fat is of importance as increased internal fat lowers dressing percentage. Dressing per-

centage is an economic factor of importance under present marketing procedures. The chilled carcass yield as a percentage of live purchase weight is one of the factors packers consider in pricing cattle. A decrease in yield is expected to accompany a decrease in slaughter grade (Butler _et al_., 1956) while top market classes are expected to dress higher than low market classes of steers. Baker (1961) pointed out that as a rule in the beef breeds dressing percentage increases with fat cover but that Brahman and Charolais crossbreds do not follow this trend. Brahman and Brahman crossbreds can be expected to yield two to four per cent higher than British breeds due to less fill (Butler _et al_., 1956; Carpenter _et al_., 1961; Lofgreen _et al_., 1962). Callow (1961) reported that beef steers became progressively fatter in relation to Friesian steers as dressing percentage increases. Therefore for the same dressing per cent, Friesian and possibly Charolais carcasses, can be expected to be leaner (Butler _et al_., 1956; Callow, 1961). Under Canadian slaughter procedure where kidney, caudal and pelvic fat are removed on the killing floor these results may be less pronounced. Callow (1961) and Berg _et al_. (1963) reported a higher percentage of caudal, mesenteric and kidney fat and less subcutaneous fat for milk breeds.

III. Carcass Evaluation and Prediction of Cutability

A. Retail Yield or Cutability

Murphey (1962) has stated "the purpose of carcass evaluation work is to obtain objective, unbiased, factual measures of the cutout value and eating desirability of beef carcasses and to relate these to live animal evaluation for selection purposes". To do this, factors affecting cutout value must be identified, measured and classified as to importance. Carcass cutout must be undertaken to determine the relation between cutout

and simple measurements in order to identify the best predictors of carcass value.

Retail yield and cutability have evolved in meats terminology to have various meanings. Cutability may mean the summation of all salable meat cuts from a carcass (Butler et al., 1956), the summation of all salable meat cuts from a carcass with the exception of stew and ground beef (Brungardt, 1962), or the summation of all salable meat cuts from the round, loin, rib and chuck (Murphey et al., 1960).

Wide variations in yields of trimmed retail cuts, among all carcasses as well as among carcasses in the same grade, are due primarily to variation in proportion of lean, fat and bone, in the carcass (Pierce, 1957). Fat is the most costly tissue to put on an animal and has been shown to have both favorable and adverse effects on consumer acceptability of beef (Hankins and Howe, 1946).

Carcass evaluation is complicated by differences in consumer preferences which vary with respect to weights of cuts, fat trim desired, income level, season of the year and relative prices of other meats (Meyer and Ensminger, 1952). Price fluctuations between cuts also influence consumer's buying preferences. Thus, retail trim is difficult to standardize. Brungardt and Bray (1963) report the standard deviation for fat trim on 300 to 800 pound carcasses to be 2.87 per cent in preparation for retail sale. The difficulty involved in standardizing retail trim and value is one factor which has led research workers into a search for simpler methods of carcass evaluation. Use of retail yields is the most desirable method of carcass evaluation (Brungardt, 1962), but is expensive and laborious (Crown, 1953). A great deal of work has been done in an attempt to develop simple, cheap methods of measuring carcass yield and meat quality in beef cattle. Accurate predictors of carcass yield would materially aid animal breeders

in reducing the surplus of trimmed fat and to increase the total lean from a carcass by identifying differences in breeding animals (Brungardt, 1962; Cole et al., 1960b; Goll et al., 1961b; Hankins and Howe, 1946; Murphey et al., 1960).

B. The Relation of Live Conformation to Cutability

Packers have bought slaughter cattle on expected dressing per cent and anticipated carcass grade for many years. From the production standpoint great changes have been brought about in the physical form or conformation of beef animals since Bakewell first began his improvement of meat animals. Beef conformation has long been said to be associated with higher proportions of high-priced cuts (Semple and Dvorachek, 1930).

However, as long ago as 1903, Helser et al. reported that the percentages of the various wholesale cuts were virtually the same from carcasses of beef or dairy breeding. Branaman (1962) reported similar results. Riggs (1961) reported minor carcass differences between British beef steers and Brahman steers which have different types of conformation. Brahman steers showed the highest yields of round, loin and rib and less chuck. Lush (1928) pioneered live animal measurements on 185 steers on feed to record changes in conformation. He made seventeen measurements on the live animals but didn't arrive at any conclusions until a later study was completed. Lush (1932) concluded that compact, fat steers had more fat and edible meat. The level of fatness he reported was below the levels which must be trimmed from a carcass;hence,would have no influence on retail yield of edible meat.

Pierce (1957) stated that "variations in yields of cuts were primarily due to conformation and finish". Research has shown conformation to have a very low positive correlation with cutout value (Cole et al., 1960b; Gregory et al., 1962; Murphey et al., 1960; Ramsey et al., 1962). In

another study by Powell _et al_. (1961) the correlation between cutout and conformation score was -0.50. The better a carcass looked to the grader the poorer the cutout. Woodward _et al_. (1959) reported no predictive relationships between performance or conformation characteristics and carcass traits. The conflicting results and low correlations between cutout and conformation may be due to the fact that it is not always possible to determine the proportion of carcass thickness contributed by fat cover and the degree due to muscle and skeletal shape.

Gregory _et al_. (1962) indicate that experienced cattle appraisers can make reasonably accurate estimates of group means for carcass weight, fat thickness at the 12th rib, percent kidney fat, rib-eye area at the 12th rib, cutability and carcass grade, provided the graders have some knowledge of the feeding and management program to which the cattle have been subjected and their live weight. Black _et al_. (1938) found visual observation superior to measurements because "measurements cannot show exactly the proportions that should exist in a good beef animal". Pierce (1963) reported that live cattle can be appraised more accurately on the basis of quantitative or cutability differences than on qualitative differences commonly associated with organoleptic differences. It is obvious that the purchase of cattle on the basis of actual carcass measures of the variables influencing value, both quantitative and qualitative, would be more accurate and thus more equitable than when live estimates are used (Murphey, 1962).

Shelby _et al_. (1960) stated that selection for body form and other breed characteristics becomes dangerous when traits selected for have no relation to productive or carcass values. Performance can be considered without regard for conformation unless a low value, wasteful carcass type develops (Warwick, 1960).

C. Linear Measurements

Linear measurements of the carcass have been studied for many years without discovery of any significant predictive measure of carcass yield. In general much of the observed correlation among the various linear carcass measurements arises from their relation to general size (Orme et al., 1959b). The biological variation in carcasses makes the use of linear measures for estimates of composition difficult (Bray, 1963; Gregory et al., 1962). Shelby et al. (1963) reported correlations of 0.54 between slaughter and carcass grade, with lower coefficients for area of rib-eye, 0.16; thickness, 0.22; dressing percentage, 0.19; length of body, 0.15; length of leg, 0.03 when compared to slaughter grade. These correlations are in general agreement with those of Goll et al. (1961a), Orme et al. (1960) and Ramsey et al. (1962). Brungardt and Bray (1963) found length of rump, loin, round length and thickness all positively correlated with retail yield, while all fat measurements were negatively correlated with retail yield. Goll et al. (1961b) also report carcass grade to be negatively correlated to skeletal measures and positively correlated to body thickness measurements. Carcass grade was negatively associated with depth of body, -0.46; per cent round in a carcass, -0.59; and the percentage thick cuts, -0.53.

Cole et al. (1962) in agreement with Green (1954) reported that carcass length was positively related to pounds of separable lean and negatively related to fat cover over the rib-eye. Relations between linear carcass measurements and either rib-eye area or carcass separable lean are quite low. Shelby et al. (1963) reported that, with the exception of length of body and length of hind leg, little correlated response in desired carcass traits would result from selection for preslaughter traits. This is in support of Cole et al. (1962) in his conclusion that the breeds

with the longest carcasses have the least fat cover and highest cutability.

D. Carcass Grade

Carcass grade is determined by conformation, finish and quality. These factors plus dressing percentage are used to determine the value of an animal. Conformation is evaluated on such factors as thickness of muscling, width in relation to depth and relative development of valuable cuts. Carcasses with deep, wide, plump rounds, full meaty rumps and thick, full loins and ribs are considered of good conformation. If sufficient finish is carried by the carcass to qualify for a Brand grade, conformation need only be minimal for the grade. Bray (1963) states that the simplest carcass evaluation is grade but that grade is one of the most meaningless tools in meats research due to the balancing of conformation, finish and quality factors.

Ternan et al. (1959) reported that to be graded Inferior, steers had to exhibit dairy breeding. However, Branaman et al. (1962) found beef and dairy type steers had few statistically significant differences in retail cuts with no difference in percentage of high priced cuts which points out the fallacy in market price variation for steers associated with their presumed cutability (Cartwright et al., 1958). Wheat and Holland (1960) interpreted the low correlation between cutability and slaughter grade as being due to the very low variation in finish carried by market steers from large feedlots. Marlowe et al. (1962) reported fleshing of the live animals, which includes fat cover and muscling to be the major factor influencing carcass grade. Woodward et al. (1959) reported that there was no relationship between linear measures and carcass grade but that carcass grade was significantly related to carcass finish. Ternan et al. (1959) reported that fat trim, the amount of fat cover which must be removed from a carcass in a retail trim, exerted the primary

influence on carcass grade. Murphey et al. (1960) reported that within each carcass grade large cutability yield variations existed.

E. Area of Longissimus Dorsi Muscle

In this thesis longissimus dorsi area as measured in Canada between the 11th and 12th ribs and in the United States between the 12th and 13th ribs will be referred to as rib-eye area.

Palsson (1939) first reported that degree of muscle development could be estimated by measuring the cross sectional area of the longissimus dorsi muscle at the last rib in lamb carcasses. Rib-eye has been advocated as an indication of meatiness in lamb carcasses, ever since. As explained by the body growth gradient theory of Hammond (1932), the longissimus dorsi muscle is the last muscle to reach its full development. Rib-eye has been considered by some workers to be the best estimate of meatiness of a carcass (McMeekan, 1941; Palsson and Verges, 1952; Wallace, 1948). McMeekan (1941) reported a correlation of 0.84 between carcass lean and a rib-eye shape index for lamb carcasses. In contrast, Powell et al. (1961) reported a correlation of -0.61 between retail yield and rib-eye area in beef carcasses. This is in agreement with the results of Orme et al. (1960). Ramsey et al. (1962), in an evaluation of the yield grades, which include rib-eye area, as proposed by Murphey et al.(1960), found that the correlations between yield grade and per cent separable lean were 8 per cent higher if the rib-eye factor was deleted from the prediction equation of Murphey et al. (1960). Rib-eye area did not contribute to regression equations for predicting retail yield (Brungardt and Bray, 1963), pounds of carcass lean (Woodward et al., 1959) nor percentage primal cuts (Orme et al., 1959b).

Kline and Hazel (1955) first put rib-eye area under close scrutiny as a predictor of carcass lean due to the positional variability of rib-eye

area. Cole et al. (1962) found that beef carcass rib-eye area variability ranged up to one and one half square inches between the 12th and 13th ribs of individual carcasses. Cole et al. (1960b) found rib-eye area responsible for only 5 to 30 per cent of the variation in the amount of lean in a carcass but that it was related more closely to carcass weight; correlations were 0.43 and 0.77 respectively. Carcass weight was more useful in predicting lean in various cuts than was rib-eye area.

F. Fat Measurements and Distribution of Fat

Hankins and Ellis (1939) showed from data for 142 grain-fed steers that fatness was a major factor affecting the proportion of edible meat or 'cutout' in a carcass, the correlation was -0.92 between fat, as measured by ether-extract content of the 9-10-11th rib cut and weight of separable lean of the carcass. This concurs with the findings of Butler (1957), Pierce (1958) and Murphey et al. (1960), who all reported fat cover to be the major factor in cutability. Murphey et al. (1960) found various measures of fatness all highly negatively correlated with yields of bone-in retail cuts in beef - the same relationship as reported by Buck et al. (1962) for hogs. Johansson and Hildeman (1954) reported that fat measures taken at seventeen locations on the carcass were less efficient in evaluating carcass value than fat measures taken over the rib-eye. A single fat measurement over the rib-eye was as good as an average of three measures over the rib-eye in predicting carcass lean in studies reported by Orme et al. (1959b). They also reported that subjective fat evaluation of carcass finish was highly correlated, 0.90, with retail cutout. Murphey et al. (1960) reported a correlation between fat thickness over the rib-eye and retail cutout of -0.54. Powell et al. (1961) reported a correlation of 0.50 between estimated fatness of the live animal and retail cutout. These results are supported by Cole et al. (1962) and Ramsey et al. (1962) who

reported that neither carcass grade nor yield grade was superior to the fat thickness measurements over the rib-eye as estimators of per cent separable fat and lean. When conformation and finish were expressed in terms of grades, finish was 4½ times as important as conformation in predicting yield of bone-in retail cuts from the round, loin, rib and chuck (Murphey et al., 1960).

G. Separation of Cuts Into Separable Lean, Fat and Bone

Separating the beef carcass into lean, fat and bone was first done in the early 1900's by Trowbridge et al. at Missouri. The reader is referred to Bratzler (1958) for a more complete review of the history of carcass evaluation and to Bray (1963) for terminology. Quantitative methods used to determine lean, fat and bone in beef carcasses have varied with the equipment and personnel available.

The laborious task of complete separation was eliminated by Hankins and Howe (1946) when they established a relationship between separable lean, fat and bone in the 9-10-11th rib cut and in the entire carcass. Hankins and Howe (1946) developed estimation equations for prediction of the amount of separable lean, fat and bone from work done on 9-10-11th rib cut . They also reported the per cent separable lean, fat and bone of the 9-10-11th rib cut to be highly correlated with the per cent separable dressed-carcass lean, fat and bone. The correlation coefficients were 0.90, 0.93, and 0.80 respectively.

Crown and Damon (1960) found high correlations between the separable lean, fat and bone of both the 12th and the 9-10-11th rib cuts and the total carcass as shown in Table 1. These results indicate that the 12th rib cut can be used very successfully as a predictor of carcass yield and meat quality of beef cattle with less devaluation of the remaining carcass.

TABLE 1

Correlation Coefficients Between Separable Lean, Fat, and Bone of 12th Rib Cut and 9-10-11th Rib Cut and with Total Carcass Separable Lean, Fat and Bone on 24 Beef Carcasses

	9-10-11th Rib cut			Total Carcass		
Item	Separable lean	Separable lean	Bone	Separable lean	Separable lean	Bone
12th Rib cut						
Separable lean	0.825**			0.818**		
Separable fat		0.965**			0.962**	
Bone			0.850**			0.750**
9-10-11th Rib cut						
Separable lean				0.943**		
Separable fat					0.976**	
Bone						0.733**

**Significant at the 1% level

The separation of larger wholesale cuts has also received a great deal of attention in a review of the subject by Pearson (1960). The extent to which differences in muscling will be used in beef cattle improvement will depend on the simplicity of measuring the predictors of carcass lean, as well as their reliability. Wholesale cuts *per se* have been used by Texas workers (Butler *et al.*, 1956) but too much variation exists in composition of the whole cut in relation to the distribution of lean, fat and bone. Brungardt (1962) found only 8 - 11 per cent of the variation in retail yield accounted for by untrimmed wholesale cuts.

Cole *et al* (1960b) reported the separable lean of the round, chuck and foreshank was associated with 90, 87 and 66 per cent respectively of the variation in total separable lean in the carcass. The separable lean of a particular cut, foreshank for example, was found more descriptive of carcass leanness or muscling than either area of rib-eye or linear carcass measurements. Cole *et al*. (1960b) found 2.94 and 20.43 pound increase in

separable carcass lean for every pound increase in separable round and foreshank lean, respectively.

Brungardt (1962) found that the per cent retail-trimmed round was the best single predictor of retail yield; it accounted for 69 per cent of the variation in retail yield. By using a combination of per cent trimmed round and a fat measure over the 12th rib, 81 per cent of the variation could be accounted for by Brungardt and Bray (1963).

If only one side of a carcass is cut, concern may arise over side differences as illustrated by the results of a study by Goll *et al*. (1961a); the right sides yielded significantly more round, loin and chuck while kidney fat was consistently heavier on the left side.

H. Prediction Equations and Yield Grade

As mentioned previously, the most accurate method of carcass appraisal is retail cutout, but this is not practical, so various workers have developed prediction equations. The aim is to detect the cutability differences which exist between carcasses within the same grade (Murphey *et al*., 1960).

Brungardt (1962) accounted for 81 per cent of the variation in retail yield from the four thick cuts; round, loin, rib and chuck, with an equation utilizing per cent trimmed round and one fat measure over the 12th rib,

$$\begin{array}{l}\text{per cent bone-in} \\ \text{retail yield of the} \\ \text{four thick cuts}\end{array} = 16.64 + 1.67\ (\%\ \text{trimmed round}) - 4.94 \begin{pmatrix}\text{single fat} \\ \text{measure over} \\ \text{12th rib}\end{pmatrix}$$

Cole *et al*. (1962) reported carcass weight to be the best predictor of carcass separable lean. The best prediction equations utilizing carcass weight and fat thickness accounted for 79 per cent of the variation in separable lean. Different regression equations were calculated for the three types of cattle used; British breeds, Zebu-British crossbreds, and dairy breeds. The prediction equations that were found to be the most accurate in estimating pounds of separable carcass lean are listed below

with the correlation coefficient reported between the estimated and actual yield of lean.

For all the breeds:

$$\text{pounds of separable lean from a side} = 11.73 - 1.73\left(\begin{matrix}\text{fat thickness over}\\ \text{rib-eye in mm}\end{matrix}\right) + 0.2890\left(\begin{matrix}\text{carcass}\\ \text{weight in lbs}\end{matrix}\right)$$

R = 0.88

For the British breeds:

$$\text{pounds of separable lean from a side} = 39.16 - 1.40\left(\begin{matrix}\text{fat thickness over}\\ \text{rib-eye in mm}\end{matrix}\right) + 0.2266\left(\begin{matrix}\text{carcass}\\ \text{weight in lbs}\end{matrix}\right)$$

R = 0.82

For the Brahman crosses:

$$\text{pounds of separable lean from a side} = 37.43 - 1.91\left(\begin{matrix}\text{fat thickness over}\\ \text{rib-eye in mm}\end{matrix}\right) + 0.2462\left(\begin{matrix}\text{carcass}\\ \text{weight in lbs}\end{matrix}\right)$$

R = 0.85

For the Holsteins and Jerseys:

$$\text{pounds of separable lean from a side} = 3.11 - 3.44\left(\begin{matrix}\text{fat thickness over}\\ \text{rib-eye in mm}\end{matrix}\right) + 0.3199\left(\begin{matrix}\text{carcass}\\ \text{weight in lbs}\end{matrix}\right)$$

R = 0.92

Murphey et al. (1960) developed an equation for the prediction of yield of bone-in retail cuts from the round, loin, rib and chuck from values for fat cover over the rib-eye, rib-eye area, per cent kidney fat and carcass weight. Inclusion of other factors such as grade, length of body and other fat measures did not increase the predictive value of the following equation:

$$\text{Percentage bone-in retail cuts from the round, loin, rib and chuck} = 65.49 - 7.24\left(\begin{matrix}\text{average fat cover}\\ \text{over rib-eye, in}\end{matrix}\right) - 1.24\ (\%\ \text{kidney fat}) + 0.35\ (\text{area rib-eye, in}^2) - 0.0038\ (\text{carcass weight, lbs})$$

R = 0.85

In the late 1950's the U.S.D.A. realized that their beef grading system failed to account for cutability differences of carcasses within any given grade. A system of yield grades, proposed by Murphey et al. (1960) was instituted for a one year trial period in July, 1962. The carcass grade which had been in use for several years was designated as the quality grade

except that conformation was no longer a factor to consider. The quality grade is based on maturity, color of external fat, marbling, color of lean and texture. The yield-grade for any quality grade is based on the prediction equation of Murphey et al. (1960). Yield-grade 1 is based on a minimum of 53.1 per cent boneless retail cuts from the four thick cuts and each yield-grade from 1 to 6 has a range of 2.3 per cent in boneless retail-yield.

The equation used is:

$$\begin{array}{l}\text{Per cent boneless} \\ \text{retail cuts from} \\ \text{round, loin, rib,} \\ \text{and chuck}\end{array} = 51.34 - 5.78\begin{pmatrix}\text{single fat thickness} \\ \text{over rib-eye, in}\end{pmatrix} - 0.462\,(\%\text{ kidney fat}) + 0.740\,(\text{area of rib-eye, in}^2) - 0.0093\,(\text{carcass wt., lbs})$$

IV. Measures of Meat Quality

Meat quality research has followed a much less precise path as the word quality itself has many connotations. Pearson (1960) defines quality of beef as that which is attractive to the eye and produces a maximum of satiety upon consumption. Quality will be defined in this review as the summation of the distinctive traits or special features that determine the ultimate acceptability of beef to the consumer (Doty, 1960). At present no positive, objective techniques are available for rapid accurate evaluation of quality in carcass beef (Doty, 1960).

Variations of biological origin in beef carcass quality cannot be eliminated simply by standardizing evaluation techniques. Many factors affect the palatability rating which is made up of flavor, tenderness, juiciness and the physical tests such as shear force and press fluid of beef muscle. It is generally believed that the physical, chemical, histological and organoleptic characteristics of beef are influenced by the genetic background of the animal as well as by the treatment of the animal and the carcass. Some of these characteristics are interrelated and can be

recognized visually. Other properties are more obscure (Doty and Pierce, 1961).

Most meat quality evaluations are based on subjective observations, therefore the reported relations among the various characteristics vary over a wide range. Tenderness has been reported related to the following measures associated with beef quality; mechanical shear values (Black et al. 1931; Ramsbottom et al., 1945), intramuscular fat content or marbling (Husaini et al., 1950; Wanderstock and Miller, 1948) and muscle fiber size (Hiner et al., 1953). Carcass grade was reported to be inconsistently related to measures of tenderness (Cover and Hostetler, 1960).

Juiciness has been stated to be related to fat content (Barbella et al., 1939). The distinctive flavor of cooked meat has been attributed, by implication to many substances; creatine and creatinine (Sherman, 1948), sulfur compounds (Bouthilet, 1951; Crocker, 1948) and many other factors (Cramer, 1963).

A. Color of Lean and Fat

Color of lean is the most important factor in consumer acceptability from the appearance standpoint and has received extra attention since the advent of self-serve counters. Most meat discoloration problems are associated, not with production, but with the handling of the carcass (Pearson, 1960). Hall et al. (1944) investigated the characteristics of dark cutting beef and concluded that brightness or darkness of beef on exposure to air is pH dependent. If muscle glycogen levels are low, the breakdown to lactic acid is reduced and hence the myoglobin is not oxidized and does not brighten on exposure to air (Lewis et al., 1954). Proper handling prior to slaughter can materially reduce the incidence of dark cutting beef (Ramsbottom et al., 1949a). Wilson et al. (1959) concluded that there were marked breed differences in color of pork. Objective color

measurement is too hard to utilize in beef research (Nickerson, 1958). Doty and Pierce (1961) found lean color of raw rib-eye related to carcass grade and weight. They also reported that aging for two weeks lightens the color of lean. From a consumer, retailer and grader survey conducted by Meyer and Ensminger (1952) it was reported that many retailers and graders and a few consumers discriminate against yellow fat on the assumption that such carcasses lack quality and breeding. Consumer studies of Van Syckle and Brough (1958) and Branson (1957) indicate that fat color _per se_ is not objectionable to the consumer.

B. Palatability and Tenderness

Tenderness is one of the most important characteristics of beef from a consumer's point of view. No visible characteristic is known that is a thoroughly reliable indicator (Cover and Hostetler, 1960). Hiner _et al._ (1955) have stated that "tenderness in beef is a function of interrelated factors, namely: breeding, feeding, management, age at slaughter, aging period, collagenous and elastic fibers, size of muscle fibers, marbling and cooking method."

Consumer acceptance provides the ultimate test for measuring tenderness but poses many problems, hence the use of the Warner-Bratzler shear press to obtain an objective measure of tenderness has been the standard for some time. Schultz (1957) has written an excellent review on the mechanical methods for measuring tenderness. Shear strength of cooked meat is a good index of tenderness (Bailey _et al._, 1962; Burrill _et al._, 1962; Doty and Pierce, 1961). Correlations between shear values and sensory tenderness values of _longissimus dorsi_ muscle samples are -0.91 for the Warner-Bratzler shear (Burrill _et al._, 1962) and -0.72 for the Kramer shear press (Bailey _et al._, 1962; Burill _et al._, 1962). Burrill _et al._ (1962) found a correlation of 0.67 between raw and cooked rib-eye samples; this is lower

than Berg *et al*. (1963) found with the Kramer shear.

The *longissimus dorsi* muscle exhibits an increasing tenderness gradient from the posterior to anterior portion and from the chine bone edge outwards (Doty and Pierce, 1961).

C. Factors Influencing Palatability and Tenderness

1. Breeding and Management

Variations in tenderness due to breed and sires within a breed were noted by Brady (1937), Harrison (1959), Orme *et al*. (1959b), Pearson (1960), and Tuma *et al*. (1962a). Berg *et al*. (1963) using the Kramer shear reported differences in tenderness due to breed and sires. Palmer (1961) reported tenderness differences between Hereford and Angus sire groups. Baker (1961) and Riggs (1961) indicate that Brahman and Charolais crossbreds tend to be less tender than British breeds. Cover and Hostetler (1960) reported that some sires showed a significant correlation between shear force values and carcass grade.

It is generally accepted that older animals are less tender than young animals. Maturity has been shown to be related to tenderness by Helser *et al*. (1903) and Simone *et al*. (1959). However, some 3 to 5 per cent of all canner and cutter cows are as tender as young beef (Pearson, 1960).

Little work has been done on the direct effects of management and nutrition on tenderness but it is known that stress affects tenderness (Hiner and Hankins, 1950; Matthews and Bennett, 1962).

2. Rigor Mortis or Aging

Beef is tender at slaughter (Paul *et al*., 1952; Ramsbottom and Strandine, 1948), becomes less tender as rigor occurs and becomes more tender with aging. An excellent review of the chemistry of aging was written by Bate-Smith (1948).

The methods of aging and tenderizing meat properly and economically are important to the packer. Proteases are responsible for alterations in tenderness during aging (Sleeth et al., 1958). Sleeth et al. (1958) and Callow (1947) concluded that shrinkage occurs due to moisture loss from the carcass in the first 2 or 3 days of hanging, with a 2.5 per cent shrink expected from choice and good grade carcasses. They also found that aging for 5 days at 68°F was comparable in effect to 12 to 14 days at the normal aging temperature of 34°F.

Tough meat at slaughter tenderizes more with aging than does beef that is tender at slaughter (Ramsbottom and Strandine, 1948). Ramsbottom and Strandine (1948) and Doty and Pierce (1961) demonstrated that beef that is not cut or handled tenderizes more by aging than does beef cut immediately after slaughter and that the greatest increase in tenderness occurs during the first 12 days of aging. Doty and Pierce (1961) reported that aged raw rib-eye had a higher pH contained more nonprotein nitrogen, free amino nitrogen, creatinine and color, than fresh beef. Most retail beef is aged for at least 12 days. Therefore, grades will be a poor indicator of tenderness unless lower grades are sold unaged. If lower grades are sold unaged an adequate amount of marbling will be indicative of tenderness if the lean is bright in color (Doty and Pierce, 1961). Lowe and Kastelic (1961) state that "aging is more rapid in young animals but that variations occur in animals of the same age, breed and grade."

3. Collagenous and Elastic Fibers

A review of the effect of collagenous and elastic fibers on tenderness was presented by Cover and Hostetler (1960). Hiner et al. (1955) indicate that the size of elastin fibers increases with the age of the animal and is related to tenderness. This is supported by Ramsbottom et al. (1945) but is contrary to the results of Wierbicki et al. (1954) who reported

a low correlation between hydroxyproline content, a good index for amount of collagen and tenderness.

4. Histological Structure of Muscle

Joubert (1956) reviewed work done on muscle fiber diameters, and pointed out that fiber diameter varies with breed, weight, muscle used, exercise and sex of the animal. It has been shown that there is no post natal increase in the number of muscle-fibers and that growth is accomplished by hypertrophy of individual fibers (Hammond, 1932; Joubert, 1956). Muscle fiber diameter was found to increase from a mean of 58.9 $\pm$ 13.2 to 71.4 $\pm$ 18.0 microns in animals from 6 to 90 months of age (Tuma *et al.*, 1962a). Breed has a very definite influence on muscle fiber diameter. Joubert (1956), Paul (1962a,b), Berg *et al.*, (1963) and Brady (1937) have all reported significant differences in muscle fiber diameters between Hereford, Shorthorn and Angus steers as compared to Holstein and Jersey steers. Holstein steers have much coarser muscle fibers while Jersey muscle fiber diameters are much smaller than those of the beef breeds. Significant sire differences in muscle fiber diameters were reported by Paul (1962b) and Lowe and Kastelic (1961). Tuma *et al.* (1962b) did not find muscle fiber diameter to be a good indicator of lean in the carcass, while Wang *et al.* (1956), using standardized conditions, found muscle fiber size indicative of carcass lean. Hiner *et al.*(1953) and Hiner and Hankins (1950) concluded that muscle fiber diameter increased with the weight of an animal, with fastest growth occurring in 8 to 14 month old animals on full feed.

The effect of muscle fiber diameter on tenderness is not clear cut, but tenderness decreases as muscle fiber diameter increases as shown by linear correlations of 0.45 and 0.67 between muscle fiber diameter and tenderness (Brady, 1937; Hiner *et al.*, 1953, respectively). A curvilinear

relationship between muscle fiber diameter and tenderness was reported to have a 0.83 correlation (Hiner _et al._, 1953).

5. Finish and Marbling

The amount and distribution of fat covering has been emphasized by the meat trade in the past. The reasoning according to Pearson (1960) been that fat covering prevents the carcass from excessive shrink and that tenderness is increased. Zinn (1963) indicated that only 3/8 of an inch of fat cover is required to hold a carcass and that above this level of covering there is little relation between shrink in the cooler and fat cover or tenderness.

Marbling is the term used to indicate the presence of flecks or streaks of fat within muscles. A basic pattern of marbling is present in the rib-eye muscle (Blumer _et al._, 1952; Tuma _et al._, 1963). Marbling has been regarded as an important indicator of tenderness (Cover _et al._, 1958; Helser _et al._, 1903; Hostetler _et al._, 1936; Mackintosh and Hall, 1936), as it was supposed to spread the muscle fibers creating more tender beef. Ramsbottom _et al._ (1945) stated that there was no relation between tenderness and fat content of a muscle. Correlation coefficients between ether extract as a measure of marbling and shear force as a measure of tenderness were -0.08 (Wellington and Stauffer, 1959), -0.34 (Cover _et al._, 1958; Cover and Hostetler, 1960; Tuma _et al._, 1962a). Tuma _et al._ (1962a) reported that only 10 per cent of the total variation in tenderness is associated with marbling. Marbling is however related to juiciness (Cover _et al._, 1957; Cover and Hostetler, 1960), which gives a pleasing sensation to the person eating the beef. Panel tenderness scores and shear force values are not always highly related (Cover and Hostetler, 1960). The tenderizing sensation due to juiciness would not be detected by shear force values but would explain some of the panel score-shear value discrepancies (Cover and

Hostetler, 1960). Blumer and Fleming (1959) suggested that sampling errors and variations along the longissimus dorsi muscle were responsible for the low relationship between panel scores and shear force values.

As an animal fattens a much higher proportion of fat is deposited subcutaneously than is deposited within muscular tissue, so that fattening has a comparatively minor effect on marbling (Callow, 1947). Intramuscular fat is affected by breed, sire, and maturity of the animal (Cover and Hostetler, 1960). Orme et al. (1958), Cole et al. (1960a) and Cover and Hostetler (1960) all found specific gravity related to measures of fatness, but associated with only 10 - 20 per cent of the variation in tenderness.

Values for ether extract expressed as a percentage of the trimmed weight of lean from a muscle are the best estimates of marbling but do not indicate distribution patterns of the fat (Wellington and Stauffer, 1959). Doty and Pierce (1961) found ether extract in the raw rib-eye to vary between 1.5 to 26.4 per cent between animals. Harwin et al. (1962) using the probe technique of Aunam and Winters (1952) for sampling lean from the longissimus dorsi muscle found a correlation of 0.73 between marbling score and per cent ether extract. Kennick and England (1960) reported a correlation between weight of fat in the 10-11th rib cut and per cent fat in the carcass of 0.77. They also presented a regression equation for estimation of percentage fat in the boneless portion of a steer carcass.

Callow (1961) found little difference in marbling between breeds but Angus steers showed the greater amount. Baker (1961) reported Charolais crossbreds had less marbling than Hereford and Angus controls.

Carcass grades have little relation to tenderness as they are based primarily on fat cover (Cover et al., 1958; Cover and Hostetler, 1960; Wellington and Stauffer, 1959). Callow (1961) reported that the traditional assumed relation between fatness and palatability was not borne out but that

palatability did increase more rapidly with increased fatness in Friesian steers than it did in Herefords. He concluded that the greater the selection for beef in a breed, the less important fatness is to palatability.

6. Cooking Methods

Shear force values indicate that loin steaks become less tender as they are cooked thoroughly, round steaks however are tenderest when well done (Cover and Hostetler, 1960; Ramsbottom et al., 1945). Beef that is deep fried cooks rapidly and may be less tender than oven cooked meat (Doty and Pierce, 1961; Stradine et al., 1949; Ramsbottom et al., 1945). Results of cores cooked in deep fat at 147°C to an internal temperature of 63°C were found to be as good indicators of tenderness as oven cooked samples because cooking conditions can be more easily standardized with deep fat than with oven cooking (Paul and Bratzler, 1955; Wellington and Stauffer, 1959).

7. Carcass Grade

Present grade standards are based on the composite evaluation of variation in conformation, finish and quality. Estimates of quality are based on external color of fat and lean, maturity and in some cases, when a carcass is ribbed, on marbling, texture, lean color and firmness. Reports by Black et al. (1931), Nelson et al. (1930) and Wanderstock and Miller (1948) indicate that carcass grade is an acceptable criterion of of organoleptic quality. Sherman (1948) first expressed doubt as to the dependability of carcass grade as an index of juiciness and tenderness in beef. Murphey et al. (1960) reported that U.S.D.A. carcass grades do reflect measurable differences in eating quality but do a poor job of it. This is in agreement with the results of Good et al. (1961), Pierce (1960) and Stewart and Mrak (1960) who concluded that the relationship between

grade and quality is not close. The problem is a lack of positive, objective techniques for rapid, accurate evaluation of quality in carcass beef (Bray, 1963).

EXPERIMENTAL

I. Objectives

The purposes of the present investigation were:

1. to evaluate the influence of inheritance in live performance and carcass characteristics of beef cattle,
2. to assess the interrelations of live and carcass characteristics,
3. to attempt to determine useful predictors for retail carcass cutout, and to
4. estimate the minimum numbers of progeny for efficient testing of sires for various traits.

II. The Data

A. Source

In Canada, selection in animal breeding has been on the basis of visual appraisal. Since 1955 various forms of performance testing programs have been in effect in different parts of Canada. Progeny testing, particularly of artificial insemination (A.I.) center sires, was the next step in programs for improvement of beef cattle. Progeny testing in Alberta herds using A.I. began at L.K. Ranches Ltd. in 1959 in cooperation with the Ontario Association of Artificial Breeders and the Production and Marketing Branch of the Canada Department of Agriculture. Later the Alberta Beef Cattle Performance Association (A.B.C.P.A.) became the group representing the producers. The aim of the progeny test program was to evaluate the merit of sires available to ranchers through artificial insemination as well as some sires used in natural service. The initial plan, as outlined by Baird (1962) for the 1960 breeding program at L.K. Ranches included six bulls, each bull to be bred to 75 cows selected so that all bulls would cover cows in the same age groups. From each sire group ten steer calves

were to be selected at random to go into Western Feedlots Ltd. for test. The fed-calves were to be slaughtered before the next breeding season. The remainder of the calves were to be finished by 14 to 16 months of age.

Since some breeding difficulties arose during the summer of 1960 at L.K Ranches, other herds using some of the same bulls were included in the test in an attempt to fill the planned progeny groups. The data reported in this study are from steers which were part of this cooperative Progeny Testing Program and were from the following ranches:

L K. Ranches - Chas. and Neil McKinnon, Bassano

Kentucky Ranch - Eugene Burrus, High River

Bar U Ranch - Allen Baker, High River

Running M Ranches - Ed and Art McKinnon, Airdrie

Quarter Circle 57 Ranch - Harry Hays, High River

In this study each ranch is referred to by cattle brand, L K, ꓘ-B, $\overline{\text{U}}$, ∿∿, and $\overset{\smile}{57}$ respectively. Table 2 gives an outline of the number of progeny, breeds and sires included from these cooperating ranches.

Each calf was identified at birth as to sire, dam and birth date. After weaning on November 21, 1961, the calves were transferred to Western Feedlots Ltd., Strathmore, where a weight was recorded which formed the basis for calculating preweaning gain and also served as a starting weight for the feedlot test. The calves were further identified at this time with numbered ear tags.

The calves represented in this study, with the exception of the 10 Hereford backcrosses from Holstein X Hereford dams, are from predominately Hereford dams. The crossbred calves are from Angus, Charolais and Holstein sires. The sire progeny groups contained from 5 to 28 steers with the exception of those for 2 of the Charolais sire progeny groups

TABLE 2

Allotment of Calves by Feeding Program, Ranch and Sire

Sire Code	Fed Calves 103H	104H	106H	108H	109H	CH[1]	Hols	Fed Yearlings 101H	103H	104H	105H	106H	107H	108H	109H	110H	122H	100A	CH[2]	Hols
Ranch																				
L K	10	10	10	6	8	7			10	10	5	10	10	6	9	2			8	
57							10									10[3]				9
K-B										5	5						5			
∿∿								4				8						5		
Ū																10				

[1]Charolais Sires Represented - 100C SIR ALTO 1 steer
103C ETIENNE J.B. 3 5 steers
105C WHITE JR. 500 1 steer
[2]Charolais Sires Represented - 100C SIR ALTO 2 steers
103C ETIENNE J.B. 3 6 steers
[3]Holstein X Hereford Dams, all other dams predominantly Hereford

Hereford Sires Represented -
101H UNEQUAL 20 GRAND
103H BRITISHER MISCHIEF'S IMAGE 21L
104H BRITISHER STANWAY 36N
105H DEL ZENTO BRITISHER LAD 72N
106H WALLACE DOMINO PALADOME 10H
107H CMR CHOICE ROLLO 21
108H QUEENSVU CHOICE ROLLO 107N
109H MO LE DOMINO LAD 39th
110H SILVER PRINCE 7N
122H A.C.T. MONTY 32nd

Angus Sire Represented - 100A BLACKBIRD BANDOLIER OF ANOKA 30th
Holstein Sire Represented - Hols

106H, 107H, 108H, 122H and 100A no longer in service

which contained fewer calves.

The calves were divided into 2 feeding programs, a fed-calf group which went onto heavy feed immediately and a fed-yearling group which was wintered at a level of nutrition just over maintenance for 174 days and put on heavy feed on May 14, 1962. There were 58 steers slaughtered from the calf and 125 from the yearling groups.

The reasons for putting a representative group of calves from each sire, on feed as early as possible after weaning in the calf program were to obtain preliminary results on the sires before the next breeding season, to test young sires as early as possible, to compare the repeatability of results from calves and yearlings from the same bulls, and to identify bulls of superior merit for the production of baby beef (Baird, 1962).

All steers from both feeding programs were to be marketed when they reached a low-choice finish as estimated on the live animal. The first draft of calves was marketed on May 14, 1962. Thereafter, weekly marketing continued until the final draft of yearlings was shipped on August 20, 1962.

Once selected the steers for that week's shipment were run through a chute, external loin width measured, ear tags checked and full feedlot weights recorded. After weighing the steers were placed in a pen to await trucking to Calgary, a distance of 30 miles.

B. Description

In this study 42 performance, carcass and quality characteristics were studied. The measurements and calculations for the 42 traits as outlined below do not necessarily follow the chronological order in which they were recorded, but are grouped according to their interrelationships for the reader's convenience.

1. Feedlot average daily gain (ADG) - total gain in weight in the feedlot, based on the full feedlot weight, divided by the length of time in the feedlot.
2. Lifetime average daily gain (LADG) - final feedlot weight divided by the age in days.
3. Live shrunk weight - weight recorded at the packing plant after an overnight stand without feed and water. The scale used for individual weighing was a heavy-duty stock scale accurate to $\pm$ 10 pounds.
4. Warm carcass weight - weight of the hot shrouded carcass with kidney and pelvic fat removed, recorded immediately after slaughter.
5. Cold carcass weight - weight of the carcass after 12 to 18 days aging in the packing plant cooler at 35 to 40°F.
6. Side weight - weight of the left side of each carcass, recorded in the retail store.
7. Dressing percentage - warm carcass weight as a percentage of the shrunk live weight.
8. Kidney fat - weight of the kidney and pelvic fat trimmed from a carcass, in the standard procedure used on Canadian killing floors, as a percentage of the warm carcass weight.
9. Cooler shrink - difference between warm and cold carcass weights as a percentage of warm carcass weight.
10. Carcass grade - assigned by the Grading Service, Production and Marketing Branch, Canada Department of Agriculture, approximately 20 hours after slaughter. A carcass was appraised for conformation as plus, average, or minus for the grade for each of the four thick cuts. A 1 was assigned to an average conformation appraisal

score of Choice^{+}, a 2 for an average of Choice, a 3 for an average of Choice^{-}, etc., down to the poorest conformation which graded Standard and was assigned 8.

Unless stated otherwise, linear carcass measurements and other appraisals were made while the carcasses were hanging on the rail in the cooler. The measurements as listed below were taken from the left side of each caracss to the nearest 0.1 inch.

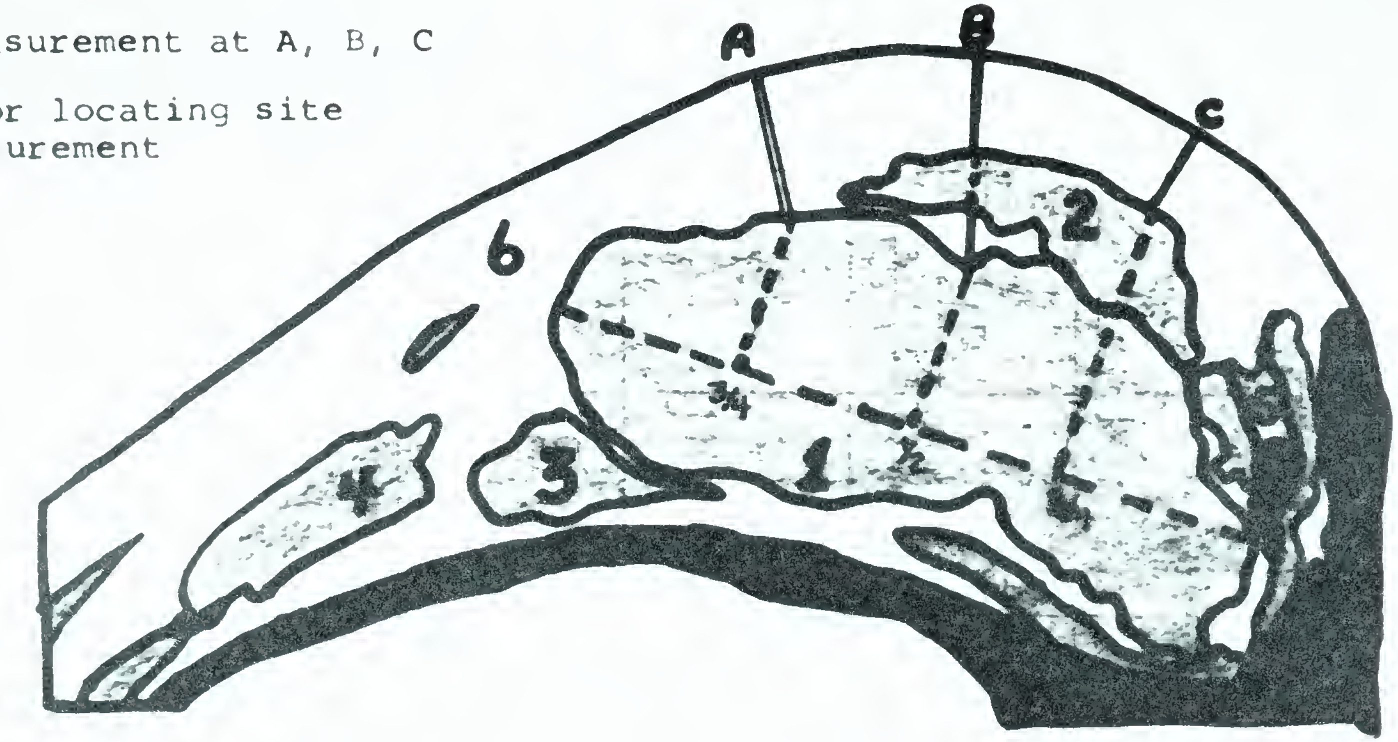
11. Average fat cover - average of three measurements of the subcutaneous fat cover over the longissimus dorsi muscle between the 11th and 12th ribs. Locations of the three measurements are illustrated in figure 1.
12. Single fat cover - measurement recorded at location A of figure 1.
13. Fat cover per hundredweight - average fat cover divided by cold carcass weight.
14. Rib-eye area - Cross sectional area of the longissimus dorsi muscle between the 11th and 12th ribs after a 12 to 18 day stand in the cooler. The rib-eye was measured utilizing a plastic grid with ¼ square inch markings, counting those squares which at least half covered longissimus dorsi muscle. A photographic grid after Schoonover and Stratton (1957) was utilized for permanent black and white photos of the rib-eye (figure 2). The negatives were later projected onto an opaque surface and a planimeter used to check the grid area measurements.
15. Rib-eye area per hundredweight - area of the longissimus dorsi muscle in square inches divided by the cold carcass weight.
16. Depth of rib-eye - distance across the widest part of the longissimus dorsi and spinalis dorsi muscles including any fat which occurred between these two muscles.

Figure 1

Photograph of cross section of the rib-eye, cut between the 11th and 12th ribs, used to measure rib-eye area with a planimeter.

Figure 2

Cross Sectional Tracing of **Rib Cut Taken**
Between the 11th **and** 12th **Ribs** Showing
Location of Fat Cover **Measurement**



— fat measurement at A, B, C

- - - line for locating site of measurement

Muscles:

1 Longissimus dorsi (rib-eye)
2 Spinalis dorsi
3 Longissimus costarum
4 Latissimus dorsi
5 **Multifidus** (superior) dorsi
Fat
6 **External** or Subcutaneous Fat Cover

17. Percentage separable lean - weight of separable lean as a percentage of the weight of fat plus lean tissue obtained by probe sampling as illustrated in Section 1, Appendix C.

18. External loin width - the distance between points at the lateral break of the loin on each side of the animal, just anterior to the hook bones.

19. Depth of rib - the distance between the ventral side of the first thoracic vertebra and the dorsal edge of the sternum but excluding any excess fat at the sternum.

20. Circumference of round - the circumference of the round 2/3 of the way along the round from top to bottom with the patella acting as an anterior marker; this measurement gave the circumference of bone and muscle.

21. Width of round - distance across the face of the round at the widest point between top and bottom round, recorded at the time of retail cutout.

22. Length of round - measured from a point on the central _tarsus_ to a point parallel to the anterior tip of the _tuber coxae_ or aitch bone to permit use of a straight measuring tape.

23. Length of hock - _tibia_ length, when this bone was removed from the carcass during retail cutout; the measurement was made from mid-joint to mid-joint on the freed _tibia_.

24. Length of loin - measured from a point between the 11-12th thoracic vertebrae to the anterior tip of the _tuber coxae_. This measurement gives the length of short loin in a carcass.

25. Length of carcass - measured from a point at the anterior edge of the first thoracic rib to a point at the anterior tip of the _tuber coxae_.

26. Shank weight - weight of the wholesale shank cut removed by the procedure outlined in Section 2, Appendix B.

27. Weight of the wholesale round - weight of the untrimmed wholesale round as illustrated in Section 2, Appendix B.

28. Weight of the retail round - weight of the trimmed retail round.

29. Percentage hindquarter - weight of the hindquarter as a percentage of the side weight.

30. Percentage round - weight of the trimmed retail round as a percentage of the weight of the side.

31. Percentage loin - weight of the trimmed retail loin as a percentage of side weight.

32. Percentage rib - weight of the trimmed retail rib as a percentage of side weight.

33. Percentage chuck - weight of trimmed retail chuck as a percentage of the weight of the side.

34. Percentage retail round or salable round - weight of the trimmed retail round as a percentage of the weight of the wholesale round.

35. Percentage wholesale thick cuts (whole RLRC) - the sum of the weight of the wholesale round, loin, rib and chuck as a percentage of the weight of the side.

36. Percentage retail thick cuts (retail RLRC) - the sum of the weight of the trimmed retail cuts from the round, loin, rib and chuck as a percentage of the weight of the side.

37. Estimated retail thick cuts (Est. RLRC) - estimated by the equation developed by Murphey _et al_. (1960) as outlined on page 21, without corrections for kidney fat and location of quartering the carcass side.

38. Retail yield - the total weight of the retail cuts from a side including ground beef and stew meat as a percentage of the weight of the side.
39. Ether extract - weight of ether extract as a percentage of the total weight of the sample of lean according to the procedure outlined in Section 3, Appendix C.
40. Raw shear - maximum pounds of shear force per gram of sample determined by the L.E.E.-Kramer shear press as outlined in Section 4, Appendix C.
41. Cooked shear - shear values for cooked *longissimus dorsi* muscle as outlined in Section 4, Appendix C.
42. Fiber diameter - measured on formalin fixed samples of *longissimus dorsi* muscle according to the procedure in Section 5, Appendix C.

Two other qualitative characteristics, marbling and color of lean, were recorded for each carcass but so little variation existed in each trait that they are not reported. All carcasses were scored medium or bright for color of lean. The carcasses in this study had only small amounts of marbling.

III. Statistical Analysis

Careful preliminary inspection of the data and limited correlation and variance analysis indicated the characteristics of beef which showed evidence of interrelationships and some association with carcass grade or weight; selected data were subjected to more complete analysis. Complete data from each sire group were subjected to variance analysis to determine the effects of feeding program, breed and ranch.

A. Statistical Model

A 'nested' or hierarchial classification was used to obtain estimates of the contributing variance components. The statistical model was:

$Y_{ijk} = u + g_i + s_{ij} + e_{ijk}$

where; Y_{ijk} is the phenotypic value of any individual observation,

u is the effect common to all individuals,

g_i is an effect common to Groups and includes feeding program, ranch of origin, and breed.

s_{ij} is an effect common to all animals from a particular sire within a Group,

e_{ijk} is a random effect peculiar to an individual within a sire group.

The method of estimating variance components and their coefficients with unequal sub-class numbers used in this analysis is described by Anderson and Bancroft (1952).

The method of calculating Expected Mean Squares was:

Source	Degrees of Freedom Expected	Degrees of Freedom Actual	Expected Mean Squares
Total	N-1	182	
Groups	g-1	10	$\sigma^2 + k'\sigma_s^2 + k''\sigma_g^2$
Sires within Groups	s-g	17	$\sigma^2 + k\sigma_s^2$
Progeny within sires	N-s	155	σ^2

where: N is the total number of individuals,

g is the number of feeding methods, ranches and breed groups, and

s is the number of sires within Groups.

The corresponding k values as estimated by the method of Anderson and Bancroft (1952) were:

For all progeny	Within calves	Within yearlings
$k = 6.11$	5.92	6.24
$k^1 = 7.12$	7.10	6.95
$k^{11} = 14.97$	15.04	14.50

The experimental data were analyzed for significance of the components

of variance using the F-test and the valid error indicated by Expected Mean Square. The variance tables include the mean square and components of variance. Significance of the variations of the mean squares for the Groups and sire effects are indicated by two asterisks corresponding to $P < .01$, or one asterisk indicating $P < .05$.

Because the original experimental plan was not sufficiently complete to statistically eliminate the confounding effects due to lack of numbers in some sire groups, the failure of all sires to be represented on all ranches and in both feeding programs and the uneven distribution of breeds between ranches Group (σ^2_G) variance was not subdivided into its contributing factors, feeding program, ranch of origin and breed.

The sire component of variance (σ^2_S) represents the difference between sires within a breed and because of the experimental plan, only 3 of the 17 degrees of freedom are not contributed by Hereford sire differences, since some combinations had only 1 sire per breed, ranch or feeding program and their variance was thus removed in the Group subdivision. The within sire component of variance (σ^2) is a measure of the variation between individuals within a sire group.

The components of variance for Groups, sires within Groups and progeny within sire groups are reported as percentages of the total variance obtained by summing the three separate components, but without including negative components where they occur. If a negative sire component occurred, the Group component of variance was calculated with an assumed sire variance of zero.

An overall pooled mean and standard deviation are reported for all animals in this study. The standard deviation was calculated as the square root of the total variance, calculated from the sum of Group, sire and within sire components of variance regardless of sign.

Breed means are presented within a feeding program for performance traits and pooled means for other characteristics. Means for performance

traits of sire groups are presented for all sires with respect to ranch of origin. If differences were suspected between means, Duncan's Multiple Range Test was applied to detect significance (Duncan, 1955).

Gross intercorrelations among 42 selected characteristics are presented in Appendix A as computed in Project 906111 by the Computing Center of the University of Alberta. Selected groups of intercorrelations from Appendix A are presented in Tables in appropriate places for ease of reference. The terminology used in discussing magnitude of the various correlation coefficients is as follows, 0 - 0.24, low; 0.25 - 0.50, medium; 0.51 - 0.75, high; and 0.76 - 1.00, very high. This terminology is similar to that of Shelby _et al_ (1963). In these data correlation coefficients which were $>$0.15 were significant at the 5 per cent level, $>$0.19 were significant at the 1 per cent level.

The minimum number of animals required to detect differences between progeny of two tested sires was estimated according to Henderson (1960). The formula used was: $\phi = \sqrt{\frac{kA}{E} \cdot \frac{f_1}{f_1 + 1}}$

where: k is the minimum number of animals required to test progeny differences between two sires,

A is equal to the sire component of variance,

E is equal to the within sire component of variance,

f_1 is the number of degrees of freedom,

ϕ was set at 2.50 to give a power of from 88 to 94 per cent.

Estimates of heritabilities were made according to Shelby _et al_. (1963). The formula used was: $h^2 = \frac{4\,\sigma_s^2}{\sigma_s^2 + \sigma^2}$

RESULTS AND DISCUSSION

I Performance Traits

Sire progeny and overall means of gain data, live shrunk weights and carcass weights are given in Tables 3 and 4. Sire progeny means are presented for each ranch of origin and feeding method while the mean designated as Hereford (He) is the pooled mean for all Herefords in a feeding program.

Preweaning Average Daily Gain (Prewean ADG)

Preweaning gains were not analysed statistically. Fairly large differences are evident among the progeny groups. Charolais x Hereford crossbreds and Hereford x Holstein backcrosses excelled when compared to other breed groups on the same ranch. A difference in rate of gain of 0.74 lb. per day was obtained from 110H used on Hereford dams compared to the same sire on Holstein x Hereford dams which would indicate superiority for these crossbred cows. However, ranch is confounded in this comparison and preweaning conditions may have been different on the two ranches involved.

Feedlot Average Daily Gain (ADG) and Lifetime Average Daily Gain (LADG)

Sire progeny differences were significant for feedlot ADG in the calves ($P < .05$) and for LADG in both calves and yearlings ($P < .01$, Table 5). Sire differences as indicated by % sire variance were similar for these three measures of gain but were essentially undetectable in feedlot ADG of yearlings. The yearlings were held on a relatively low plane of nutrition for a specific period of 174 days and on a high plane for from 50 to 92 days depending on their apparent finish. Such a feeding system apparently masked sire progeny differences in gains.

No additional variance in feedlot ADG occurred among the breed, ranch of origin groups. There was some indication, although not statistically significant, that groups varied more than sires within groups for

TABLE 3

Sire Progeny Group Means for Performance Traits

Sire Code		Ranch	Number Calves	Prewean ADG	Feedlot ADG	Lifetime ADG
				lb/day	lb/day	lb/day
			Calves			
He(1)	103H	LK	9	1.61	2.40	2.11
	104H	LK	10	1.86	2.64	2.37
	106H	LK	10	1.80	2.77	2.42
	108H	LK	5	1.50	2.83	2.46
	109H	LK	7	1.66	2.89	2.42
He	Mean	LK	41	1.71	2.70	2.34
C x He		LK	6	2.01	2.95	2.64
Ho x He		57	10	1.74	2.68	2.39
			Yearlings			
He	101H	~	4	1.62	2.04	1.97
	103H	LK	9	1.59	2.20	2.04
	104H	LK	10	1.75	2.35	2.18
	104H	ꓘ-B	4	1.48	2.20	2.09
	105H	LK	5	1.81	2.10	2.08
	105H	ꓘ-B	5	1.53	2.06	2.03
	106H	LK	10	1.81	2.20	2.13
	106H	~	8	1.62	2.24	2.09
	107H	LK	10	1.68	2.41	2.14
	108H	LK	6	1.78	2.29	2.18
	109H	LK	9	1.75	2.28	2.19
	110H	Ū	12	1.44	2.25	2.09
	122H	ꓘ-B	4	1.45	2.09	1.97
He	Mean		96	1.64	2.20	2.09
A x He		~	4	1.69	2.14	2.04
C x He		LK	8	1.88	2.42	2.30
Ho x He		57	8	1.69	2.38	2.18
110H x Ho x He		57	10	2.18	2.28	2.23
Overall Mean			183	1.73	2.51	2.16
	s_x			0.21	0.31	0.24

(1) He - Hereford, C - Charolais, Ho - Holstein, A - Aberdeen-Angus

TABLE 4

Sire Progeny Group Means for Live and Carcass Weights

Sire Code	Number Calves	Shrunk Live Wt	Warm Carcass Wt	Cold Carcass Wt	Left Side Wt
		lbs	lbs	lbs	lbs
		Calves			
He 103H	9	828	494	478	241
104H	10	914	547	529	257
106H	10	938	561	544	275
108H	5	912	543	526	264
109H	7	903	527	510	260
He Mean	41	899	534	518	261
C x He	6	971	589	573	289
Ho x He	10	943	566	551	277
		Yearlings			
He 101H	4	853	503	486	244
103H	9	879	516	499	252
104H	13	899	525	508	255
105H	10	881	528	509	257
106H	18	904	547	529	268
107H	10	907	530	510	257
108H	6	902	537	518	260
109H	9	910	543	523	267
110H	12	859	506	491	248
122H	4	827	488	470	237
He Mean	96	888	525	509	257
A x He	4	875	517	500	253
C x He	8	980	596	578	291
Ho x He	8	970	592	573	289
110H x Ho x He	10	972	571	552	279
Overall Mean	183	908	541	517	263
s_x		75.5	43.4	46.4	23.7

TABLE 5

Mean Squares and Components of Variance for Performance and Slaughter Traits

Source	Degrees of Freedom Calves	Yearlings	Total	Feedlot ADG Calves	Feedlot ADG Yearlings	Lifetime ADG Calves	Lifetime ADG Yearlings	Shrunk Live Wt	Warm Carcass Wt	Cold Carcass Wt	Left Side Wt
G(1)	2	7	10	0.2200	0.0886	0.3200	0.2857	25137.4**	11587.6**	11516.9**	2928.1**
S/G	6	11	17	0.2050*	0.1100	0.1167**	0.1064**	5284.1	2284.4**	2213.3	603.2
P/S/G	48	106	155	0.0735	0.1028	0.0331	0.0336	4202.3	1078.4	1411.8	372.0
σ_g^2				-.0111	-.0016	0.0124	0.0118	1314.3	608.1	612.6	152.8
σ_s^2				0.0222	0.0012	0.0141	0.0117	177.0	197.4	131.2	37.8
σ^2				0.0735	0.1028	0.0331	0.0336	4202.3	1078.4	1411.8	372.0
Total Variance				0.0957	0.1040	0.0596	0.0571	5693.6	1883.9	2155.6	562.6
% σ_g^2				(2)	(2)	20.8	20.7	23.1	32.3	28.4	27.2
% σ_s^2				23.2	1.2	23.7	20.5	3.1	10.5	6.1	6.7
% σ^2				76.8	98.8	55.5	58.8	73.8	57.2	65.5	66.1
h^2 %				92.8	4.6	119.0	103.0	16.2	61.9	34.0	36.9

(1) G - groups, S/G - sires within groups, P/S/G - progeny within sires and groups.
(2) negative estimate
* Significant at P<.05.
** Significant at P<.01.

TABLE 6

Intercorrelations[1] Among Performance Traits, Live and Carcass Weights and Retail Yield

Trait	LADG	Shrunk Live Wt	Warm Carcass Wt	Cold Carcass Wt	Side Wt	Retail RLRC %	Retail Yield %
ADG	-.187	0.198	0.094	0.073	0.050	0.259	-.032
LADG		0.613	0.571	0.580	0.545	-.273	-.007
Shrunk Live Wt			0.939	0.934	0.881	-.101	-.082
Warm Carcass Wt				0.997	0.948	-.107	-.072
Cold Carcass Wt					0.952	-.120	-.077
Side Wt						-.084	-.033

(1) r = 0.15 significant at P< .05
r = 0.19 significant at P< .01

LADG. This was probably due to the more rapid lifetime gains of the Charolais crossbreds.

Shrunk Live Weight and Carcass Weights

Group differences for all live and carcass weights are significantly different ($P < .01$, Table 5) reflecting the heavier weights of Charolais and Holstein crossbreds at marketable condition. Within breed, sire differences were significant ($P < .01$) only for warm carcass weight but cold carcass weight and left side weight approached significance. These data seem to indicate that sire progeny differences are easier to detect for carcass weights than for shrunk live weight.

Intercorrelations Among Performance Traits, Live and Carcass Weights and Retail Yield

Feedlot ADG had a low negative relation to lifetime ADG ($r = -.187$, Table 6), a low positive relation to shrunk live weight ($r = 0.198$), and bore essentially no relation to carcass weights. Lifetime ADG on the other hand was correlated highly with live and carcass weight measures. Neither measures of performance nor live or carcass weights had a significant relation to retail yield. Retail thick cuts (Retail RLRC) had a low positive relation to feedlot ADG ($r = 0.259$) but was negatively related to LADG ($r = -.273$).

II Slaughter Traits

Dressing %, Kidney Fat and Cooler Shrink

Since kidney fat is removed before weighing the carcass, it can affect dressing % results. Sires within group differed significantly in dressing % ($P < .01$, Table 8) and in kidney fat % ($P < .05$). Group variance for these two traits, though not significant, showed some extra variance over that of sires. Breed probably contributed most to group variance since Charolais and Holstein crossbreds dressed about 1 percentage point

above the Herefords (Table 7). Hereford x Holstein backcrosses, however, dressed below the Herefords. Steers with Holstein in their background had a higher % kidney fat than Herefords, while the Charolais crossbreds were in between as were the Angus crossbreds in this study. Generally, within the Hereford breed, the fatter progeny groups had higher dressing % which agrees with Butler et al (1956). This relation did not hold between breed groups where Charolais and Holstein were included.

Sire within group differences did not exist for cooler shrink. Group differences were significant ($P < .05$) with Charolais and Holstein crossbreds showing less shrink in the calf group than Herefords. No breed differences were evident in the Yearling group. Selection for cooler shrink would probably be ineffective since genetic effects seem to be essentially absent.

Assigned Carcass Grade

Little variation in official Federal Grades existed in these data since all Angus crossbreds graded Canada Choice, 5 of the Herefords graded Good, the rest Choice, Holstein crossbreds graded 10 Choice and 8 Good and the Charolais crossbreds graded 7 Choice, 4 Good and 3 Standard. The conformation grade score in these data involves Official Grade and conformation in a range of 1 to 8 with top Choice given 1 and low Standard given 8. In this study Charolais and Holstein crossbreds graded better as calves than as yearlings. Group differences, probably reflecting breed, were significant ($P < .01$) for conformation grade score but no differences were detected among sires within breeds. It would thus be ineffective to improve carcass conformation grade by selection when marketing is based on constant finish as in this study.

Measures of Fatness

Groups differed in average fat cover ($P < .01$, Table 8), reflecting greater depth of fat over the rib in the Herefords and Angus crossbreds.

The single fat measure was more variable and neither group nor sire within group differences were significant which differs from results of Brungardt (1962) and Orme et al (1962). Also in their work the single fat measure tended to be a minimum, whereas in the present data it was usually the largest of the three measuring points. When adjustment is made for carcass weight in the fat cover per cwt. measure, both group ($P < .01$) and sire differences ($P < .05$) were significant. Sire differences in fatness were best detected on the basis of fat cover per cwt. and the heritability estimate of this trait indicates reasonable within breed genetic effects.

Measures of Leanness

Rib-eye area has been used as a measure of carcass lean and rib-eye depth has been credited with similar importance. Separable lean % in a rib core should directly estimate leanness (Table 7). Both group and sire differences were significant ($P < .05$) for rib-eye area. However, when adjustment was made for carcass weight as rib-eye area per cwt., group effects were no longer significant reflecting that larger rib-eyes are associated with larger carcasses particularly between the breed groups. Sire within group differences were highly significant ($P < .01$) for rib-eye area per cwt. Good progress should result from selection emphasizing either measure of rib-eye area.

Group differences were significant ($P < .01$) for rib-eye depth and were associated with greater depth in the heavier breeding groups. Sire within group differences were not detectable.

Large group ($P < .01$) and sire ($P < .05$) differences were found for % separable lean in the rib core. The crossbreds were generally higher in % separable lean than the Herefords. The heritability estimate was reasonably high for this characteristic (h^2 = 46.9%).

Intercorrelation Among Measures of Fatness, Leanness, ADG and Carcass and Retail Yield

Some correlations (Table 9) among dressing % and other traits

TABLE 7

Sire Progeny Group Means for Slaughter Traits and Carcass Grade

Sire Code	Number Calves	Dress	Kidney Fat	Cooler Shrink	Assigned Carcass Grade	Average Fat Cover	Single Fat Cover	Fat Cover	Rib-eye Area	Rib-eye Area	Rib-eye Depth	Separ Lean
		%	%	%		in	in	in/cwt	sq in	sq in/cwt	in	%
						Calves						
He 103H	9	59.4	1.4	3.34	2.0	0.75	0.77	0.14	9.25	1.76	6.1	66.3
104H	10	59.8	1.9	3.28	1.8	0.73	0.86	0.13	9.70	1.80	6.3	69.0
106H	10	59.9	2.4	3.09	1.7	0.79	0.91	0.14	8.55	1.53	6.4	67.3
108H	5	59.6	2.2	2.91	1.4	0.75	0.84	0.15	9.10	1.68	6.4	67.7
109H	7	58.5	2.2	3.20	1.9	0.74	0.97	0.14	8.92	1.73	5.8	66.2
He Mean	41	59.4	2.0	3.19	1.8	0.75	0.87	0.14	9.11	1.70	6.2	67.3
C x He	6	60.4	2.2	2.57	4.4	0.57	0.71	0.10	10.07	1.72	6.2	70.6
Ho x He	10	60.0	2.4	2.66	3.0	0.67	0.81	0.12	10.38	1.83	6.8	72.0
						Yearlings						
He 101H	4	58.9	1.7	3.33	2.0	0.92	0.98	0.19	9.00	1.79	7.0	66.3
103H	9	58.7	1.4	3.28	1.8	0.73	0.71	0.14	9.52	1.85	6.3	68.9
104H	13	58.5	1.3	3.13	2.1	0.72	0.89	0.14	9.98	1.91	6.7	68.2
105H	10	59.9	1.3	3.60	2.0	0.79	0.91	0.15	9.95	1.89	6.5	69.2
106H	18	60.5	1.4	3.27	1.8	0.68	0.79	0.13	10.19	1.86	6.7	70.5
107H	10	58.4	1.6	3.82	1.9	0.70	0.75	0.14	9.68	1.83	6.4	69.9
108H	6	59.5	1.5	3.55	1.2	0.80	0.87	0.15	10.20	1.91	6.6	70.2
109H	9	59.3	1.5	3.57	1.7	0.70	0.91	0.13	10.77	1.99	6.7	71.6
110H	12	59.4	1.6	2.97	1.8	0.80	0.86	0.15	9.20	1.82	6.2	67.5
122H	4	58.9	1.4	3.56	1.5	0.68	0.83	0.14	9.75	2.00	6.5	69.3
He Mean	96	59.2	1.5	3.37	1.8	0.74	0.84	0.15	9.88	1.89	6.5	69.3
A x He	4	59.0	1.9	3.26	1.8	0.74	0.73	0.15	10.56	2.05	6.6	71.0
C x He	8	60.4	1.9	3.15	4.4	0.52	0.65	0.09	11.28	1.85	6.7	73.7
Ho x He	8	60.6	2.3	3.26	4.6	0.63	0.80	0.11	11.00	1.86	6.8	72.0
110HxHoxHe	10	58.8	2.3	3.34	2.5	0.68	0.66	0.12	10.40	1.82	6.6	71.1
Overall Mean	183	59.5	1.9	3.23	2.2	0.77	0.81	0.13	9.89	1.83	6.5	69.5
s_x		1.73	0.62	0.71	1.5	0.14	0.22	0.03	1.21	0.20	0.74	3.21

TABLE 8

Mean Squares and Components of Variance for Slaughter Traits and Carcass Grade

Source	Degrees of Freedom	Dress %	Kidney Fat	Cooler Shrink	Assigned Carcass Grade	Average Fat Cover	Single Fat Cover	Fat Cover in/cwt	Rib-eye Area	Rib-eye Area sq in/cwt	Rib-eye Depth	Separ Lean
G	10	7.700	1.291	1.30*	15.80**	0.074**	0.096	0.00509**	6.07*	0.126	1.505**	53.00**
S/G	17	5.761**	0.531*	0.44	0.88	0.022	0.053	0.00096*	2.02*	0.074**	0.401	12.30*
P/S/G	155	2.331	0.301	0.45	1.37	0.016	0.042	0.00054	1.05	0.028	0.501	6.77
σ_g^2		0.092	0.048	0.057	0.964	0.003	0.003	0.00027	0.26	0.003	0.067	2.66
σ_s^2		0.560	0.038	-.002	-.080	0.001	0.002	0.00007	0.16	0.008	-.016	0.90
σ^2		2.331	0.301	0.450	1.370	0.016	0.042	0.00054	1.05	0.028	0.501	6.77
Total Variance		2.983	0.387	0.507	2.334	0.020	0.047	0.00088	1.47	0.039	0.568	10.33
% σ_g^2		3.1	12.4	11.2	41.3	15.0	6.4	30.7	17.7	7.7	11.8	25.8
% σ_s^2		18.8	9.8	(1)	(1)	5.0	4.2	8.0	10.9	20.5	(1)	8.7
% σ^2		78.1	77.8	88.8	58.7	80.0	89.4	61.4	71.4	71.8	88.2	65.5
h^2 %		77.5	44.8	(1)	(1)	23.5	18.2	45.9	52.9	88.9	(1)	46.9

* Significant at $P<.05$.
** Significant at $P<.01$.
(1)negative estimate

TABLE 9

Intercorrelations(1) Among Carcass Traits and Retail Yield

Trait	Kidney Fat %	Cooler Shrink %	Assigned Carcass Grade	Average Fat Cover	Single Fat Cover	Fat Cover in/cwt	Rib-eye Area	Rib-eye Area sq in/cwt	Rib-eye Depth	Separ Lean	ADG	Retail RLRC %	Retail Yield
Dress %	-.190	-.154	0.227	-.042	0.060	-.133	0.270	0.051	0.134	0.199	-.276	-.039	0.007
Kidney Fat %		-.064	0.054	-.036	-.085	-.196	-.070	-.349	0.067	0.062	0.039	-.152	-.107
Cooler Shrink %			-.116	-.089	-.184	0.002	-.056	0.088	-.066	-.074	0.190	0.191	0.083
Assigned Carcass Grade				-.371	-.234	-.358	0.135	-.022	0.083	0.192	-.161	0.136	0.209
Average Fat Cover					0.653	0.884	-.284	-.184	-.102	-.558	-.018	-.469	-.538
Single Fat Cover						0.550	-.004	0.017	0.027	-.272	-.065	-.340	-.275
Fat Cover in/cwt							-.422	-.082	-.233	-.604	-.058	-.346	-.429
Rib-eye Area								0.671	0.619	0.722	0.100	0.230	0.229
Rib-eye Area sq in/cwt									0.345	0.481	0.068	0.304	0.242
Rib-eye Depth										0.482	0.072	0.151	0.049
Separ Lean											0.073	0.332	0.332

(1)
r = 0.15 Significant at P<.05.
r = 0.19 Significant at P<.01.

probably reflect the higher dressing %, lower grades (higher grade score) and larger rib-eyes of the heavier breed groups (r = 0.227 with assigned carcass grade, r = 0.270 with rib-eye area). No apparent explanation is available for the significant negative correlation of dressing % and feed-lot ADG. Slight negative correlations of dressing % with kidney fat % and with cooler shrink could probably be expected.

A low, non-significant negative correlation (r = -.089) was found for cooler shrink with average fat cover. With the single fat cover measure, however the correlation was significant but still quite low (r = -.184).

Neither dressing %, kidney fat % nor cooler shrink had any appreciable relation to retail yield.

Recalling that in these data low assigned carcass grade is desirable, the negative correlations with fat cover indicate that more desirable grade scores are obtained on fatter carcasses. Least desirable grade scores are associated with higher retail yeild (r = 0.209) which should cause a little concern in the industry.

The three measures of fatness used are all highly correlated one with the other and show a tendency to be negatively correlated with measures of leanness. Average fat cover appears to be most highly correlated with retail yield (r = -.538) followed by fat cover per cwt. (r = -.429). The four measures of leanness are reasonably correlated one to the other but rib-eye depth showed the least correlation with retail yield (r = 0.049) and separable lean the greatest (r = 0.332).

III Linear Body and Carcass Measurements

Linear body and carcass measurements were taken in an effort to define by objective means, live animal and carcass conformation and to relate these to retail yield.

External Loin Width

Group differences for external loin width were significant ($P < .01$, Table 11). Sire within group differences were not detectable. Angus crossbreds had the greater loin widths and Charolais and Holstein crossbreds were the narrowest (Table 10).

Depth of Rib

Depth of body has been used as an indication of good conformation in beef cattle for many years. Warwick (1960) indicated that moderate depth is desired but extreme depth decreases the percentage of preferred cuts. In the present study both group and sire within group effects on depth of rib were highly significant. The Angus crossbreds were the deepest followed by the Herefords, which showed sire progeny group differences, and the Charolais and Holstein crossbreds which were the shallowest.

Circumference and Width of Round

The group differences in circumference of round were not significant but in width of round differed at $P < .05$. Sire within group differences were undetectable for circumference and low and non-significant for width of round.

Length Measurements

Animals with greater length of round and hock are more upstanding types and longer loins and carcasses should indicate greater overall length. Group differences were significant for length of round ($P < .05$) and for length of hock ($P < .01$), reflecting major breed differences. Sire within group differences were not significant for length of round possibly because of apparent large variation in taking this measure. On the other hand, sire within group differences were highly significant ($P < .01$) for length of hock.

Sire within group differences were highly significant for length of loin and carcass ($P < .01$). Additional group differences were found

TABLE 10

Sire Progeny Group Means for Linear Body and Carcass Measurements

Sire Code		Number Calves	External Loin Width	Depth of Rib	Cir Round	Width Round	Length Round	Length Hock	Length Loin	Length Carcass
			in	in	in	in	in	in	in	in
					Calves					
He	103H	9	15.2	21.8	28.4	9.0	18.6	11.2	13.4	47.4
	104H	10	15.6	21.9	29.5	9.0	20.0	10.9	13.5	48.1
	106H	10	15.6	22.2	29.9	9.0	20.0	10.9	13.4	47.3
	108H	5	15.5	21.7	28.5	9.3	19.8	10.9	13.7	48.2
	109H	7	15.2	22.0	29.7	9.5	19.6	10.8	13.1	48.0
He	Mean	41	15.4	21.9	29.3	9.2	19.6	10.7	13.4	47.7
C x He		6	14.6	22.5	30.8	9.6	20.9	11.4	13.4	49.4
Ho x He		10	14.0	21.1	30.2	9.6	20.6	11.3	13.6	48.7
					Yearlings					
He	101H	4	14.1	24.6	30.0	10.0	19.6	10.0	13.0	46.4
	103H	9	14.6	22.6	28.9	9.7	19.5	10.6	13.7	47.3
	104H	13	14.4	23.8	29.8	9.2	19.9	10.0	13.3	47.1
	105H	10	14.2	23.3	30.3	9.7	20.3	9.9	13.3	46.3
	106H	18	14.4	22.5	30.4	9.7	20.8	10.2	13.8	47.3
	107H	10	14.4	23.0	30.2	9.8	20.0	10.4	13.5	46.8
	108H	6	14.2	22.0	30.3	9.4	19.0	10.3	13.1	47.3
	109H	9	14.8	23.2	29.0	9.9	19.8	10.5	13.4	47.3
	110H	12	14.2	23.0	29.8	10.1	19.6	10.2	13.0	45.8
	122H	4	14.1	24.6	28.6	8.6	20.5	10.0	12.9	43.8
He	Mean	95	14.3	23.3	29.8	9.7	20.2	10.2	13.4	46.8
A x He		4	15.8	25.4	29.4	10.3	18.0	9.8	12.7	46.1
C x He		8	14.3	21.9	30.8	9.9	21.1	11.4	13.6	49.4
Ho x He		8	14.0	21.4	30.2	9.6	20.8	11.0	13.7	48.8
110H x Ho x He		10	14.5	22.3	29.9	9.7	20.0	10.1	13.7	48.4
Overall Mean		183	14.5	22.7	29.7	9.4	20.0	10.5	13.4	47.5
	$s_{\bar{x}}$		0.97	0.59	1.81	0.71	1.36	0.65	0.44	1.83

TABLE 11

Mean Squares and Components of Variance for Linear Body and Carcass Characteristics

Source	Degrees of Freedom	External Loin Width	Depth of Rib	Cir Round	Width Round	Length Round	Length Hock	Length Loin	Length Carcass
G	10	4.696**	520.90**	4.607	1.747*	5.665*	3.928**	0.851	23.03*
S/G	17	0.493	3.09**	3.113	0.607	1.875	0.364**	0.764**	7.62**
P/S/G	155	0.699	0.62	3.217	0.402	1.545	0.151	0.090	1.38
σ_g^2		0.267	34.56	0.093	0.074	0.250	0.236	-.0015	0.96
σ_s^2		-.034	0.40	-.017	0.034	0.054	0.035	0.1100	1.02
σ^2		0.699	0.62	3.217	0.402	1.545	0.151	0.0900	1.38
Total Variance		0.966	35.58	3.310	0.510	1.849	0.422	0.2000	3.36
% σ_g^2		27.6	97.1	2.8	14.5	13.5	55.9	(1)	28.6
% σ_s^2		0.0	1.2	(1)	6.7	2.9	8.3	55.0	30.4
% σ^2		72.4	1.7	97.2	78.8	83.6	35.8	45.0	41.0
h^2 %		(1)	156.9	(1)	31.2	13.5	75.3	220.0	170.0

* Significant at $P<.05$.
** Significant at $P<.01$.
(1)negative estimate

TABLE 12

Intercorrelations[1] Among Body and Carcass Measurements, A.D.G. and Retail Yield

Trait	Depth of Rib	Cir Round	Width Round	Length Round	Length Hock	Length Loin	Length Carcass	ADG	Retail RLRC	Retail Yield
External Loin Width	-.239	-.151	-.207	0.028	0.137	0.014	0.141	-.215	-.182	-.070
Depth of Rib		-.065	0.205	-.107	-.380	-.138	-.412	0.194	0.134	0.050
Cir Round			0.061	0.206	0.043	-.315	0.174	0.097	0.005	-.083
Width Round				0.101	-.093	0.167	0.068	0.072	0.048	-.044
Length Round					0.181	0.239	0.289	0.018	0.045	0.133
Length Hock						0.125	0.274	-.222	-.186	0.097
Length Loin							0.330	-.050	-.047	-.036
Length Carcass								-.071	-.069	-.033

(1)
r = 0.15 Significant at P<.05
r = 0.19 Significant at P<.01

for length of carcass ($P < .05$) but not for length of loin.

Intercorrelations Among Body and Carcass Measurements ADG and Retail Yield

External Loin Width proved to be of low predictive value for ADG ($r = -.215$) and retail RLRC ($r = -.182$) and of essentially no value in predicting retail yield ($r = -.070$). Depth of rib was negatively correlated to measures of length. Neither depth of rib nor circumference of round nor width of round were useful in predicting retail yield.

The various measurements of length showed some degree of correlation one with another but none were predictive of retail yeild.

IV Retail Carcass Evaluations

Means for weights and percentages of selected cuts are given in Table 13. Weight of untrimmed shank was influenced by groups ($P < .01$) but not by sires within groups (Table 14). Weights of wholesale and retail round differed between groups ($P < .01$) and also between sires within groups ($P < .05$). These differences were probably related to carcass weight differences between groups and sire progenies.

The percentage of hindquarter showed large group differences ($P < .01$) but no influence of sires within groups. Calves had a greater % of hindquarter than did yearlings which agrees with Callow's (1962) appraisal of growth and differential fattening, in that less fat would be deposited in the chuck in animals fattened at an earlier age.

With regard to the percentages of trimmed cuts, the data were a little erratic. Group differences were apparent for % chuck ($P < .05$) which may be explained as opposite to % hindquarter above. Percent round, though non-significant, showed some group effect. Sire within group differences were evident for % loin and % rib ($P < .05$) but were essentially absent for % round and % chuck. Combining the four main trimmed cuts (Retail RLRC), resulted in large group differences ($P < .01$) but sire within

group effects were absent, the same situation as existed for wholesale RLRC.

Percent of saleable round indicated large sire within group differences ($P < .01$) but no difference between groups.

Retail yield involving all cuts did not result in significant differences between sires within groups nor between groups. The standard deviation for retail yield was 2.1% which is lower than obtained in other studies in the literature review, probably because of an attempt in the present study to market animals at nearly constant finish. The mean retail yield was 78.4%, which, as has been noted, was influenced mostly by fat trim. Retail yield improved as fat cover decreased up to a point where no fat trimming was necessary after which proportion of bone had more influence limiting the maximum achievable retail yield to approximately 83%.

Except for the erratic nature of results involving components of retail yield, one might conclude that marketing at constant finish tends to mask or eliminate sire progeny and group differences in this characteristic. However, although sire differences were not significant, the heritability estimate of 29% might suggest that some response to selection for retail yield could be achieved even under constant-finish marketing.

Estimated yield of retail thick cuts (Est RLRC), using the formula of Murphy et al (1960) modified to fit Canadian slaughter procedure, did not separate sire progenies or groups in this study.

Intercorrelations Among Weights and Percentages of Cuts and ADG

Many of the correlations given in Table 15 result from obvious relations. Weights of wholesale cuts are probably highly intercorrelated because of the influence of carcass weight. Percentages of trimmed cuts, on the other hand, show little intercorrelation. Trimmed cuts as percentages were positively correlated to retail yield with % round ($r = 0.384$) and % chuck ($r = 0.412$) having the larger influences. A combination of

TABLE 13

Sire Progeny Group Means for Weights and Percentage of Cuts

Sire Code	Shank Wt	Round Wt	Retail Round Wt	Hind-quarter	Round in Side	Loin in Side	Rib in Side	Chuck in Side	Salable Round	Whole RLRC	Retail RLRC	Est Yield RLRC	Retail Yield
	lb	lb	lb	%	%	%	%	%	%	%	%	%	%
Calves													
He 103H	8.6	51.7	40.1	48.7	16.7	17.9	5.5	25.5	78.0	79.4	64.2	61.0	78.5
104H	8.2	57.2	42.9	49.4	16.1	18.1	5.0	24.9	74.5	79.4	63.9	61.1	78.3
106H	9.3	59.1	46.2	49.2	16.9	17.6	5.6	25.0	76.4	78.5	64.0	60.1	78.4
108H	8.9	57.8	42.7	49.1	16.2	16.3	5.6	24.4	74.0	77.8	64.0	60.7	75.9
109H	8.9	56.8	43.1	49.0	16.5	17.3	5.9	24.4	75.8	79.2	63.4	60.6	78.2
He Mean	8.8	56.4	43.1	49.2	16.5	17.6	5.5	24.9	75.9	79.0	63.9	60.7	78.0
C x He	10.6	64.8	50.4	48.8	17.4	18.1	5.2	25.0	77.4	78.3	65.1	62.2	79.9
Ho x He	9.5	59.8	45.2	48.1	16.3	17.4	5.2	26.9	75.8	78.5	65.6	61.6	78.7
Yearlings													
He 101H	8.5	54.3	40.9	49.5	16.8	18.3	5.4	25.6	75.2	80.3	66.3	59.5	76.9
103H	8.4	54.4	42.5	48.8	16.9	18.0	5.1	25.3	78.3	79.9	65.4	61.1	78.5
104H	9.2	57.4	44.6	48.3	17.5	18.3	5.2	26.0	77.8	80.5	66.7	61.4	79.3
105H	9.0	56.8	44.0	48.5	17.1	18.2	5.4	25.1	77.5	79.9	65.8	60.9	78.4
106H	9.1	56.0	45.0	48.8	16.8	18.0	5.3	26.1	76.6	80.4	66.7	61.7	78.7
107H	8.5	56.7	42.5	48.6	16.9	18.3	5.1	26.4	76.1	79.5	66.7	61.8	78.4
108H	8.8	58.3	43.3	48.7	16.6	17.0	5.4	25.7	74.3	80.1	64.7	60.9	76.5
109H	8.6	58.4	45.1	48.3	17.2	17.6	5.4	25.5	77.3	80.1	66.1	61.7	78.5
110H	7.9	56.3	43.4	49.1	17.7	17.4	5.2	25.6	77.2	79.9	65.6	60.6	77.8
122H	7.3	53.9	42.5	49.2	17.9	17.9	5.5	26.4	78.9	81.0	67.7	61.8	80.3
He Mean	8.7	55.5	43.7	48.7	17.1	17.9	5.3	25.8	77.0	80.1	66.2	61.3	78.4
A x He	8.8	53.9	41.1	47.6	16.5	17.2	5.1	25.9	76.4	79.3	65.5	61.4	78.1
C x He	10.2	67.0	50.3	48.8	17.5	17.6	5.1	26.6	76.7	78.9	67.2	62.9	79.5
Ho x He	9.3	63.2	48.6	48.1	16.8	17.5	5.2	25.4	76.9	79.7	66.0	62.0	78.0
110H x Ho x He	9.1	61.4	46.9	48.6	16.8	17.7	5.5	25.5	76.4	79.0	65.7	61.6	78.0
Overall Mean	8.9	58.1	45.5	48.7	16.9	17.8	5.3	25.6	76.6	79.5	65.6	61.3	78.4
s_x	1.4	5.3	4.2	1.2	0.8	1.0	0.5	1.5	2.4	1.3	2.3	2.6	2.1

TABLE 14

Mean Squares and Components of Variance for Weights and Percentage of Cuts

Source	d.f.	Shank Wt	Whole Round Wt	Retail Round Wt	Hind-quarter %	Round Side %	Loin Side %	Rib Side %	Chuck Side %	Salable Round %	Whole RLRC %	Retail RLRC %	Est Yield RLRC	Retail Yield
G	10	4.71**	152.00**	92.20**	2.38**	0.800	1.30	0.30	4.658*	6.19	8.10**	18.400**	5.20*	5.40
S/G	17	0.95	32.00*	21.18*	.62	0.706	1.47*	0.41*	1.814	10.66**	1.47	3.120	2.12	5.88
P/S/G	155	1.98	17.38	10.96	1.53	0.581	0.84	0.21	1.986	4.95	1.20	4.471	7.75	3.99
σ_g^2		0.182	7.86	4.63	0.057	0.005	-.018	-.010	0.178	-.359	0.440	0.930	-.170	-.053
σ_s^2		-.168	2.39	1.67	-.149	0.020	0.103	0.033	-.028	0.930	0.044	-.221	-.921	0.309
σ^2		1.980	17.38	10.96	1.530	0.581	0.840	0.210	1.986	4.950	1.20	4.471	7.75	3.990
Total Variance		2.162	27.63	17.26	1.587	0.606	0.943	0.243	2.164	5.880	1.684	5.401	7.75	4.299
% σ_g^2		8.4	28.4	26.8	3.6	0.8	(1)	(1)	8.2	(1)	26.2	17.2	(1)	(1)
% σ_s^2		(1)	8.7	9.7	(1)	3.3	10.9	13.6	(1)	15.8	2.6	(1)	(1)	7.2
% σ^2		91.6	62.9	63.5	96.4	95.9	89.1	86.4	91.8	84.2	71.2	82.8	100.0	92.8
h^2	%	(1)	48.4	52.9	(1)	13.3	43.7	54.3	(1)	63.3	14.1	(1)	(1)	28.8

* Significant at P<.05
** Significant at P<.01
(1) negative estimate

TABLE 15

Intercorrelations[1] Among Weights and Percentages of Cuts and A.D.G.

Trait	Whole Round Wt	Retail Round Wt	Hind-quarter %	Round in Side %	Loin in Side %	Rib in Side %	Chuck in Side %	Salable Round %	Whole RLRC %	Retail RLRC %	Est Yield RLRC	Retail Yield	ADG
Shank Wt	0.549	0.485	-.208	-.145	-.116	0.005	-.915	-.139	-.324	-.115	0.110	0.000	-.039
Whole Round Wt		0.909	-.076	0.082	-.036	-.140	0.000	-.114	-.188	0.006	0.149	0.037	0.123
Retail Round Wt			-.019	-.180	-.063	-.108	-.040	0.205	-.129	0.059	0.180	0.127	0.136
Hindquarter %				0.229	0.167	-.096	-.131	0.002	0.081	-.076	-.121	0.008	-.047
Round in Side %					0.147	-.022	0.095	0.587	0.278	0.360	0.230	0.384	0.164
Loin in Side %						-.120	0.010	0.225	0.268	0.275	0.041	0.274	0.072
Rib in Side %							-.119	0.032	0.178	0.022	-.004	0.158	-.071
Chuck in Side %								0.019	0.093	0.663	0.359	0.412	0.154
Salable Round									0.207	0.265	0.157	0.329	0.085
Whole RLRC %										0.311	0.015	0.168	0.207
Retail RLRC %											0.536	0.502	0.259
Est Yield RLRC												0.537	0.010

(1) $r = 0.15$ Significant at $P<.05$
$r = 0.19$ Significant at $P<.01$

retail trimmed thick cuts (Retail RLRC) was slightly more predictive of retail yield (r = 0.502). Percent saleable round was also correlated with retail yield (r = 0.329).

Estimated and actual retail yield were correlated as anticipated (r = 0.537).

A summary of the possible predictors of retail yield and their relative predictive value is given in Table 16. Average fat cover was the best individual predictor of retail yield accounting for about 29% of the variation observed. Estimated retail RLRC using the U.S.D.A. formula of Murphy et al (1960) did not predict retail yield any better than fat cover alone. This result is not surprising when one notes the low correlations of retail yield with % kidney fat, cold carcass weight and rib-eye area, which enter the prediction formula along with average fat cover. Percent trimmed chuck was next to fat cover in predictive value but would be rather impractical to obtain routinely. Per cent trimmed round shows some promise and would not be too difficult to obtain. Percent separable lean from a rib core was slightly better as a predictor of retail yield than was rib-eye area. What is needed is a combination of individual predictors in a prediction equation but due to difficulty with computer programming, this was not possible in the present study.

V Quality Evaluations

Means for ether extract (Table 17) reflect the relative amount of intramuscular fat or marbling in the rib-eye, larger values being indicative of greater marbling. Group differences were significant ($P < .05$) for ether extract but sires within groups did not differ. Group differences were probably associated with the higher values for the Angus crossbreds and lower values for the Charolais crossbreds. Actually none of the groups were subjectively judged to have much marbling by U.S.D.A. visual standards.

TABLE 16

Correlations and Coefficients of Determination of Various Predictors With Retail Yield

	Correlation Coefficient(1) $r \times y$	Coefficient of Determination $(r \times y)^2 \times 100\%$
Estimated RLRC	0.537	28.8
Av. fat cover	-.538	28.9
Av. fat cover/cwt.	-.429	18.4
Single fat measure	-.275	7.6
% separable lean	0.332	11.0
Rib-eye area	0.229	5.2
Rib-eye area/cwt.	0.242	5.9
% trimmed round	0.384	14.7
% trimmed loin	0.274	7.5
% trimmed rib	0.158	2.5
% trimmed chuck	0.412	17.0
Carcass grade score	0.209	4.4
% kidney and pelvic fat	-.107	1.1
Cold carcass weight	-.077	0.6
Lifetime ADG	-.007	0.0

(1) $r = 0.15$ significant at $P < .05$.
$r = 0.19$ significant at $P < .01$.

Raw shear and cooked shear values reflect tenderness in the longissimus dorsi muscle with lower values associated with more tender muscle. Sire progenies within groups differed markedly ($P < .01$) in both raw and cooked shear values. Cooked samples tend to be tougher than raw samples. Although breed groups seem to differ, with Charolais and Holstein crossbreds having higher shear values and Angus crossbreds having lower shear values, these differences are not significantly greater than those expected between sire progenies within breed.

Sire progenies also had large differences for mean fiber diameter and again breed group differences are not greater than sire progeny within group differences.

Intercorrelations (Table 19) among quality measures show very little relation of ether extract (marbling) to tenderness or fiber diameter. Raw and cooked shear values are highly correlated ($r = 0.955$) indicating that testing raw samples should be adequate. A fairly high positive correlation was obtained between shear values and fiber diameter. None of the quality values was predictive of retail yield.

VI Producer and Retail Value

Average value of sire progeny groups to the producer is influenced mostly by slaughter weight, a function of rapid lifetime gains (Table 20). The proportion which achieved Canada Choice grade had some effect as well. Dressing % accounted for minor differences in the producer value per hundredweight. Charolais and Holstein crossbreds made rapid gains and consequently had heavier slaughter weights thus returning more value per animal than the Angus crossbreds and most of the Hereford progeny groups. Producer value per cwt. was directly related to grade as this was the basis of pricing.

Retail value per cwt. did not verify the price paid to the producer

TABLE 17

Sire Progeny Group Means for Quality Measures

Sire Code		Number Calves	Ether Extract	Raw Shear	Cooked Shear	Fiber Diameter
			% fat	lb/gm	lb/gm	u
			Calves			
He	103H	9	16.13	14.51	15.73	48.10
	104H	10	16.05	13.81	14.81	50.53
	106H	10	16.95	12.05	14.46	43.36
	108H	5	16.78	11.91	13.95	51.09
	109H	7	16.87	18.31	20.15	47.71
He	Mean	41	16.51	14.39	15.73	47.83
C x He		6	12.64	18.92	20.60	51.37
Ho x He		10	15.85	18.99	20.76	55.19
			Yearlings			
He	101H	4	20.43	16.42	17.54	48.65
	103H	9	16.13	12.72	14.79	47.88
	104H	13	15.17	14.61	16.60	54.31
	105H	10	16.61	7.67	10.19	38.60
	106H	18	16.56	12.56	14.75	46.96
	107H	10	16.24	6.39	7.79	38.55
	108H	6	15.44	9.54	11.08	50.39
	109H	9	15.97	17.24	17.07	53.01
	110H	12	15.89	11.53	13.24	50.05
	122H	4	19.82	15.14	17.50	54.53
He	Mean	96	16.39	12.08	14.01	47.82
A x He		4	22.99	8.87	10.21	41.66
C x He		8	14.84	16.36	18.36	55.42
Ho x He		9	15.65	18.58	19.00	55.61
110H x Ho x He		10	17.05	11.97	13.32	46.55
Overall Mean		183	16.33	13.76	15.26	48.82
	s_x		2.95	4.35	4.55	6.30

TABLE 18

Mean Squares and Components of Variance
for Quality Measures

Source	Degrees of Freedom	Ether Extract	Raw Shear	Cooked Shear	Fiber Diameter
G	10	25.30*	109.40	123.00	157.52
S/G	17	7.59	74.82**	74.47**	202.66**
P/S/G	155	7.53	6.13	7.21	13.60
σ_g^2		1.180	1.55	2.50	-5.10
σ_s^2		0.010	11.24	11.01	30.94
σ^2		7.530	6.13	7.21	13.60
Total Variance		8.720	18.92	20.72	44.54
% σ_g^2		13.5	8.2	12.1	(1)
% σ_s^2		0.1	59.4	53.1	69.5
% σ^2		86.4	32.4	34.8	30.5
h^2 %		5.0	258.8	241.7	278.0

* Significant at P<.05.
** Significant at P<.01.
(1) negative estimate.

TABLE 19

Intercorrelations[1] Among Quality Measures, A.D.G. and Retail Yield

Trait	Raw Shear	Cooked Shear	Fiber Diameter	ADG	Retail RLRC	Retail Yield
Ether Extract	-.142	-.121	-.184	-.097	-.121	-.132
Raw Shear		0.955	0.561	-.110	-.026	0.172
Cooked Shear			0.577	-.128	-.041	0.156
Fiber Diameter				0.041	0.038	0.085

(1) r = 0.15 significant at $P<.05$.
r = 0.19 significant at $P<.01$.

TABLE 20

Comparative Value of Fed-calf and Fed-yearling Progeny Groups to the Producer and to the Retailer

Sire Code		Number Calves	Grade Ch	Grade Gd	Grade Std	Slaughter Wt	Producer $ Value*	Rating***	Producer $ Value/cwt	Retail $ Value/cwt**	Rating
							Fed Calves				
He	103H	9	8	1	0	828	208.72	7	25.21	55.81	4
	104H	10	9	1	0	914	230.78	5	25.25	56.21	3
	106H	10	10	0	0	938	237.78	1	25.35	55.44	5
	108H	5	5	0	0	912	231.19	4	25.34	55.14	6
	109H	7	7	0	0	903	228.87	6	25.35	54.80	7
C x He		6	3	2	2	971	234.76	3	24.18	56.40	2
Ho x He		10	8	2	0	943	237.08	2	25.14	57.15	1
							Fed Yearlings				
He	101H	4	4	0	0	853	216.11	13	25.34	54.00	14
	103H	9	8	1	0	879	221.61	10	25.47	56.18	5
	104H	13	12	1	0	899	227.16	8	25.25	56.31	3
	105H	10	10	0	0	881	221.57	11	25.09	56.69	1
	106H	18	18	0	0	904	229.14	5	25.33	56.40	2
	107H	10	9	1	0	907	228.95	6	25.24	55.94	9
	108H	6	6	0	0	902	228.57	7	25.27	55.00	12
	109H	9	9	0	0	910	230.69	4	25.28	55.90	10
	110H	12	12	0	0	859	217.80	12	25.36	56.25	4
	122H	4	4	0	0	827	209.77	14	25.33	55.98	8
C x He		8	3	3	2	980	237.05	2	24.10	56.00	7
Ho x He		8	2	6	0	970	235.00	3	24.22	55.02	11
110H x Ho x He		10	8	2	0	972	244.07	1	25.17	56.09	6
A x He		4	4	0	0	875	221.81	9	25.26	54.01	13

* Average Calgary price, week ending May 26th, 1962 - Choice-$25.35 Good-$24.15 Standard-$22.20
The actual carcass grade was used to determine the live market value of each steer and value of the animal was calculated according to weight and grade

**The retail prices of June 1st, 1962, were used to calculate retail value per hundred pounds of cold carcass for all carcasses.

***Rating of sire progeny groups on the basis of producer value per animal

per hundredweight. Retail value per cwt. is influenced by factors which affect retail yield. Differences between sire progeny groups for this measure would be particularly affected by average fat cover at marketing which was not a random variable in the present study.

VII Numbers of Progeny Required

In a progeny test program it is of interest to know the minimum number of animals required in a progeny group to detect sire differences. Henderson (1960) provides a method for these estimations and the minimum numbers in each sire group needed to detect significant differences between two sires for a particular trait are presented in Table 21. The detectable difference which is estimated is taken as the standard error of sire differences (σs) found in the present data. If one were satisfied to test for larger differences, less progeny would be needed. Also having more than two sires represented in a progeny test would reduce the numbers of progeny needed per sire to obtain significant differences. The minimum numbers in Table 21 are discouragingly large for most traits with the exception of tenderness and fiber diameter. One would thus have to be satisfied with the possible detection of larger differences than those listed or arrange to have more sires on test. For example LADG for yearlings could result in significant sire differences if the minimum number of animals were spread over 7 or 8 sire groups at 10 per sire.

TABLE 21

The Minimum Numbers of Progeny Needed to Detect Differences Between Two Sires Based on Variation Obtained in this Study.

Trait	Number of Progeny Required	σ_s For Difference Detected
Differences Easily Detected		
ADG calves	41	0.15
LADG calves	29	0.12
LADG year	36	0.11
Rib-eye area/cwt	43	0.09
Depth of rib	19	0.63
Length of loin	10	0.33
Length of carcass	17	1.01
Raw shear	7	3.35
Cooked shear	8	3.32
Fiber diameter	6	5.56
Differences More Difficult to Detect		
Warm carcass wt	68	14.05
Dressing %	52	0.75
Length hock	54	0.19
Salable round	66	0.96
Differences Impractical to Detect	(More than 70 progeny required)	
ADG yearlings		
Final wt		
% Kidney fat		
Fat cover		
Single fat cover		
Fat cover/cwt		
Rib-eye area		
Separable lean		
Width round		
Length round		
Wt whole round		
Wt retail round		
% Round		
% Loin		
% Rib		
Whole RLRC		
Retail yield		
Ether Extract		

SUMMARY AND CONCLUSIONS

An investigation was undertaken to evaluate live performance, carcass characteristics and meat quality traits of 183 progeny test steers sired by 10 Hereford, 3 Charolais, 1 Holstein and 1 Angus sires and from grade Hereford dams. An additional group of 10 steers were by a Hereford bull from Holstein x Hereford dams.

Disproportionate data necessitated an analysis of variance using a nested or hierarchial classification. Components of variance were estimated for groups (feeding method, ranch and breed), sires within groups and progeny within sires. Heritabilities were calculated from paternal half sib correlations. Intercorrelations among 42 performance and carcass traits were calculated.

1. Performance Traits

Sire variance and heritability estimates were high for feedlot average daily gain (ADG) for the calves which were fed to market condition rapidly (fed-calf program) but were low for those carried on a lower plane of nutrition for 174 days followed by full feeding to market condition (fed-yearling program). High heritabilities were obtained for lifetime average daily gain (LADG) under both programs and would therefore seem to be a more useful measure of gainability than feedlot ADG. Feedlot ADG was lowly correlated with shrunk live weight and LADG and had no correlation with carcass weights. Lifetime ADG on the other hand was highly correlated with live and carcass weights.

Charolais and Holstein crossbreds had higher live and carcass weights, and LADG than most of the Hereford and Angus crossbred progeny groups in this study. This indicates the former groups reached acceptable degrees of live finish at heavier weights.

2. Dressing per cent and per cent Kidney Fat and Cooler Shrink

The heritability estimate for dressing % was high at 78% and for % kidney fat was medium at 45% indicating that both traits could be improved by selection based on a progeny test. Charolais and Holstein crossbreds dressed slightly higher than Herefords but Hereford x Holstein backcrosses dressed lower. Steers with Holstein in their background had a higher percentage of kidney fat than Herefords. Charolais and Angus crossbreds were intermediate. Sire progeny differences were undetectable for cooler shrink.

3. Carcass Grade

Angus crossbreds and Herefords graded better than Charolais or Holstein crossbreds. No sire progeny differences were detected under the system of constant-finish marketing used.

4. Measures of Fatness

Average fat cover per cwt. with a heritability of 46% seemed to be more useful in a progeny test than average fat cover or a single fat measure over the rib-eye which had heritabilities of 24% and 18% respectively.

5. Measures of Leanness

Differences in rib-eye area per cwt. was easier to detect between sire progeny groups (h^2 = 89%) than rib-eye area (h^2 = 53%), separable lean in a rib core (h^2 = 47%) or rib-eye depth ($h^2 \simeq 0$).

6. Linear Body and Carcass Measurements

Heritability estimates exceeded 100% for depth of rib, length of loin and length of carcass. A high heritability of 75% was also obtained for length of hock but lower values were estimated for width of round (h^2 = 31%) and length of round (h^2 = 14%). Both length and depth of body seem highly influenced by genetic factors.

7. Retail Yield

Neither sire progeny nor group differences were statistically

significant for retail yield. This may have been influenced by marketing at a relatively constant finish. The heritability estimate for retail yield was 29% which suggests that some response to selection might result even under constant-finish marketing.

8. Measures of Quality

Marbling, as indicated by ether extract, did not differ significantly between sire progeny groups. The heritability estimate was only 5 per cent. Raw and cooked shear values of longissimus dorsi muscle were easily detected between sire progeny groups as was muscle fiber diameter. Ether extract was not related to shear values or fiber diameter. Raw and cooked shear values were related to muscle fiber diameter ($r = 0.561$ and $r = 0.577$ respectively).

9. Prediction of Retail Yield

Average fat cover was the best individual predictor of retail yield accounting for 29% of its variation. Estimating yield by the U.S.D.A. formula of Murphey et al (1960) was no more accurate in predicting retail yield than was fat cover alone. Per cent trimmed chuck accounted for 17%, per cent trimmed round for 15%, per cent separable lean in a rib core for 11%, and rib-eye area per cwt. for 6% of the variation in retail yield. No useful relationships were found between measures of gain and retail yield or measures of quality and retail yield.

10. Producer and Retail Value

Producers were paid per cwt. according to grade. Retail value per cwt. was influenced by cutout and did not justify the producer price. Lifetime gains had the greatest influence on total value per animal and justifies emphasis being placed on this trait in performance and progeny testing programs.

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Appendix Table A-Gross Intercorrelations

		2	3	4	5	6	7	8	9	10	11	12	13	14
		LADG	Shr live wt	Warm carc wt	Cold carc wt	Side wt	Dress %	Kdny fat %	Clr shrink %	Carc grade	Ave fat cover	Singl fat cover	Fat cover /cwt	Rib eye area
1	ADG	-.187	0.198	0.094	0.073	0.050	-.276	0.039	0.190	-.161	-.018	-.065	-.058	0.100
2	LADG		0.613	0.571	0.580	0.545	-.033	0.431	-.203	0.076	-.138	-.020	-.334	0.055
3	Shrunk live wt			0.939	0.934	0.881	0.053	0.459	-.180	0.068	-.097	-.011	-.426	0.404
4	Warm carcass wt				0.997	0.948	0.271	0.382	-.221	0.156	-.119	0.006	-.463	0.503
5	Cold carcass wt					0.952	0.277	0.382	-.295	0.164	-.110	0.020	-.456	0.497
6	Side wt						0.284	0.410	-.287	0.200	-.136	0.002	-.462	0.494
7	Dress %							-.190	-.154	0.227	-.042	0.060	-.133	0.270
8	Kidney fat %								-.064	0.054	-.036	-.085	-.196	-.070
9	Cooler shrink %									-.116	-.089	-.184	0.002	-.056
10	Carcass Grade										-.371	-.234	-.358	0.135
11	Ave fat cover											0.653	0.884	-.284
12	Single fat cover												0.550	-.004
13	Fat cover/cwt													-.422
14	Rib-eye area													

Appendix Table A - Gross Intercorrelations

		15 Rib-eye /cwt	16 Rib-eye depth	17 Separ lean %	18 Ext loin width	19 Depth rib	20 Cir round	21 Width round	22 Lngth round	23 Lngth hock	24 Lngth loin	25 Lngth carc	26 Shank wt	27 Wt whole round	28 Wt retail round
1	ADG	0.068	0.072	0.073	-.215	0.194	0.097	0.072	0.018	-.222	-.050	-.071	-.039	0.123	0.136
2	LADG	-.369	-.018	0.081	0.269	-.436	0.005	-.100	0.088	0.500	0.154	0.430	0.327	0.448	0.384
3	Shrunk live wt	-.251	0.330	0.317	0.076	-.287	0.150	0.087	0.260	0.244	0.259	0.491	0.478	0.804	0.751
4	Warm carcass wt	-.203	0.383	0.393	0.088	-.309	0.202	0.121	0.290	0.278	0.290	0.502	0.536	0.878	0.827
5	Cold carcass wt	-.208	0.381	0.392	0.089	-.311	0.203	0.125	0.358	0.289	0.292	0.503	0.550	0.880	0.829
6	Side wt	-.188	0.378	0.398	0.064	0.277	0.183	0.141	0.374	0.281	0.282	0.481	0.574	0.920	0.833
7	Dress %'	0.051	0.134	0.199	0.094	-.119	0.179	0.052	0.315	0.151	0.109	0.090	0.216	0.304	0.301
8	Kidney fat %	-.349	0.067	0.062	-.012	-.217	0.090	0.084	0.073	0.170	0.166	0.354	0.196	0.316	0.236
9	Cooler shrink %	0.088	-.066	-.074	-.012	0.093	-.067	-.085	-.117	-.197	-.094	-.111	-.294	-.245	-.236
10	Carcass Grade	-.022	0.083	0.192	-.119	-.143	0.107	0.119	0.257	0.279	0.116	0.267	0.260	0.244	0.266
11	Ave fat cover	-.184	-.102	-.558	0.296	0.157	-.108	0.033	-.125	-.257	0.006	-.177	-.146	-.176	-.203
12	Single fat cover	0.017	0.027	-.272	0.098	-.003	-.064	0.026	-.022	-.085	0.021	-.026	-.027	-.043	-.063
13	Fat cover/cwt	-.082	-.233	-.604	-.158	0.259	-.186	-.012	-.195	-.289	-.081	-.344	-.339	-.461	-.454
14	Rib-eye area	0.671	0.619	0.722	-.158	-.057	0.051	0.202	0.172	0.072	0.186	0.171	0.218	0.488	0.468

Appendix Table A - Gross Intercorrelations

		29	30	31	32	33	34	35	36	37	38	39	40	41	42
		Hind-qurtr %	% Round	% Loin	% Rib	% chuck	% Slbl round	% Whole RLRC	% Ret RLRC	Est RLRC	Ret yield	Ether extr	Raw shear	Ckd shear	Fiber diam
1	ADG	-.047	0.164	0.072	-.071	0.154	0.085	0.207	0.259	0.010	-.032	-.097	-.110	-.128	0.041
2	LADG	-.019	-.284	-.064	-.022	-.105	-.215	0.461	-.273	-.003	-.007	-.118	0.362	0.347	0.168
3	Shrunk live wt	-.138	-.217	-.014	-.094	-.060	-.124	-.261	-.101	0.044	-.082	-.034	0.173	0.215	0.123
4	Warm carcass wt	-.143	-.201	-.025	-.123	-.057	-.111	-.285	-.107	0.069	-.072	-.043	0.194	0.254	0.148
5	Cold carcass wt	-.155	-.203	-.025	-.118	-.069	-.111	-.300	-.120	0.059	-.077	-.034	0.199	0.257	0.154
6	Side wt	-.201	-.180	-.063	-.108	-.040	-.135	-.312	-.084	0.083	-.033	-.026	0.202	0.255	0.136
7	Dress %	0.003	0.034	-.015	-.010	0.012	0.011	-.121	-.039	0.034	0.007	-.060	0.092	0.131	0.054
8	Kidney fat %	-.086	-.195	-.081	-.050	-.110	-.181	-.263	-.152	-.164	-.107	-.010	0.212	0.227	0.088
9	Cooler shrink %	0.187	0.075	0.015	-.040	0.175	0.037	0.211	0.191	0.102	0.083	-.117	-.094	-.099	-.113
10	Carcass Grade	-.082	0.143	0.006	-.042	0.049	0.070	-.143	0.136	0.308	0.209	-.192	0.188	0.238	0.226
11	Ave fat cover	0.079	-.187	-.021	-.009	-.285	-.138	0.048	-.469	-.892	-.538	0.166	-.179	-.125	-.261
12	Single fat cover	-.015	-.152	-.012	0.039	-.196	-.096	0.060	-.340	-.559	-.275	0.100	-.042	-.031	-.117
13	Fat cover/cwt	0.127	-.059	-.001	0.027	-.218	-.062	0.159	-.346	-.772	-.429	0.138	-.195	-.215	-.261
14	Rib-eye area	-.283	0.019	0.083	-.107	0.165	0.054	0.022	0.230	0.461	0.229	0.059	0.148	0.181	0.234

Appendix Table A - Gross Intercorrelations

	16 Rib-eye depth	17 Separ lean %	18 Ext loin width	19 Depth rib	20 Cir round	21 Width round	22 Lngth round	23 Lngth hock	24 Lngth loin	25 Lngth carc	26 Shank wt	27 Wt whole round	28 Wt ret round
15 Rib-eye/cwt	0.345	0.481	-.242	0.185	-.050	0.075	-.110	-.193	-.286	-.204	-.176	-.150	-.128
16 Depth rib-eye		0.428	-.111	-.110	0.053	0.139	0.155	0.011	0.190	0.161	0.186	0.378	0.364
17 Separable lean %			-.206	-.093	0.145	0.140	0.228	0.175	0.179	0.198	0.191	0.404	0.362
18 Ext loin width				-.239	-.151	-.207	0.028	0.137	0.014	0.141	0.006	-.051	-.065
19 Depth rib					0.065	0.205	-.107	-.380	-.138	-.412	-.185	-.167	-.129
20 Cir round						0.061	0.206	0.043	-.315	0.174	0.196	0.260	0.220
21 Width round							0.101	-.093	0.167	0.068	0.083	0.173	0.139
22 Length round								0.181	0.239	0.289	0.287	0.400	0.359
23 Length hock									0.125	0.274	0.278	0.230	0.200
24 Length loin										0.330	0.172	0.212	0.176
25 Length carcass											0.360	0.421	0.388
26 Shank wt												0.549	0.485
27 Wt wholesale round													0.909
28 Wt retail round													

Appendix Table A - Gross Intercorrelations

	29 Hind-qurtr %	30 % round	31 % loin	32 % rib	33 % chuck	34 % slbl round	35 % whole RLRC	36 % ret RLRC	37 Est RLRC	38 Ret yield	39 Ether extr	40 Raw shear	41 Ckd shear	42 Fiber diam
15 Rib-eye/cwt	-.159	0.155	0.134	-.076	0.197	0.130	0.247	0.304	0.410	0.242	0.088	-.004	-.009	0.166
16 Depth rib-eye	0.135	0.037	0.042	0.057	0.093	0.039	0.024	0.151	0.216	0.049	0.125	0.090	0.106	0.164
17 Separable lean %	-.205	0.070	0.048	-.084	0.222	0.081	-.035	0.332	0.610	0.332	0.017	0.135	0.159	0.219
18 Ext loin width	0.063	-.267	0.027	0.088	0.088	-.051	-.121	-.182	-.174	-.070	0.042	0.001	-.020	-.077
19 Depth rib	0.088	0.297	-.053	-.072	0.059	0.152	0.212	0.134	-.056	0.050	0.179	-.174	-.157	-.164
20 Cir round	0.024	0.064	0.028	-.121	-.001	-.129	-.057	0.005	0.040	-.083	-.009	-.016	0.007	0.025
21 Width round	-.101	0.081	-.090	-.062	0.025	0.004	0.010	0.048	0.002	-.044	0.074	-.106	-.097	-.119
22 Length round	0.044	-.018	-.138	-.002	0.062	-.062	-.099	0.045	0.073	0.133	-.106	0.134	0.174	0.137
23 Length hock	-.012	-.124	-.140	0.038	-.015	-.117	-.338	-.186	0.158	0.097	-.109	0.370	0.360	0.296
24 Length loin	-.127	-.169	-.038	0.026	0.028	-.070	-.082	-.047	-.016	-.036	-.029	0.123	0.120	0.110
25 Length carcass	-.116	-.152	-.107	-.009	-.051	-.034	-.184	-.069	0.064	-.033	-.140	0.260	0.252	0.155
26 Shank wt	-.208	-.145	-.116	0.005	-.915	-.139	-.324	-.115	0.110	0.000	-.129	0.167	0.188	0.057
27 Wt wholesale round	-.076	0.082	-.036	-.140	0.000	-.114	-.188	0.006	0.149	0.037	-.097	0.195	0.251	0.174
28 Wt retail round	-.019	-.180	-.063	-.108	-.040	0.205	-.129	0.059	0.180	0.127	-.081	0.240	0.297	0.165

Appendix Table A - Gross Intercorrelations

	30 % round	31 % loin	32 % rib	33 % chuck	34 % slbl round	35 % whole RLRC	36 % ret RLRC	37 Est RLRC	38 Ret yield	39 Ether extr	40 Raw shear	41 Ckd shear	42 Fiber diam
29 Hindquarter %	0.229	0.167	-.096	-.131	0.002	0.081	-.076	-.121	0.008	-.132	-.029	-.046	-.014
30 % round in side		0.147	-.022	0.095	0.587	0.278	0.360	0.230	0.384	-.085	0.082	0.077	0.051
31 % loin in side			-.120	0.010	0.225	0.268	0.275	0.041	0.274	-.089	-.028	-.074	-.110
32 % rib in side				-.119	0.032	0.178	0.022	-.004	0.158	0.137	0.016	0.030	-.026
33 % chuck in side					0.019	0.093	0.663	0.359	0.412	-.137	0.021	-.007	0.045
34 % salable round						0.207	0.265	0.157	0.329	0.070	0.036	0.045	-.014
35 % whole RLRC							0.311	0.015	0.168	0.100	-.130	-.122	0.004
36 % retail RLRC								0.536	0.502	-.121	-.026	-.041	0.038
37 Est RLRC									0.537	-.125	0.109	0.118	0.241
38 Retail yield										-.132	0.172	0.156	0.085
39 Ether extract											-.142	-.121	-.184
40 Raw shear												0.955	0.561
41 Cooked shear													0.577
42 Fiber diameter													

Appendix B - Retail Cutout

After shipment from the packing plant the carcasses were stored in the store cooler from zero to a maximum of two days. Retail cutout was done by experienced retail meat cutters in Canada Safeway Stores, Calgary.

The front and hind quarter of each left side were cut separately. Each wholesale cut was weighed and then trimmed and prepared for the retail counter. The carcasses, sides, and heavier wholesale cuts were weighed to the nearest 0.5 pound and the smaller cuts to the nearest ounce. An electric band saw was used for all cuts which involved bone.

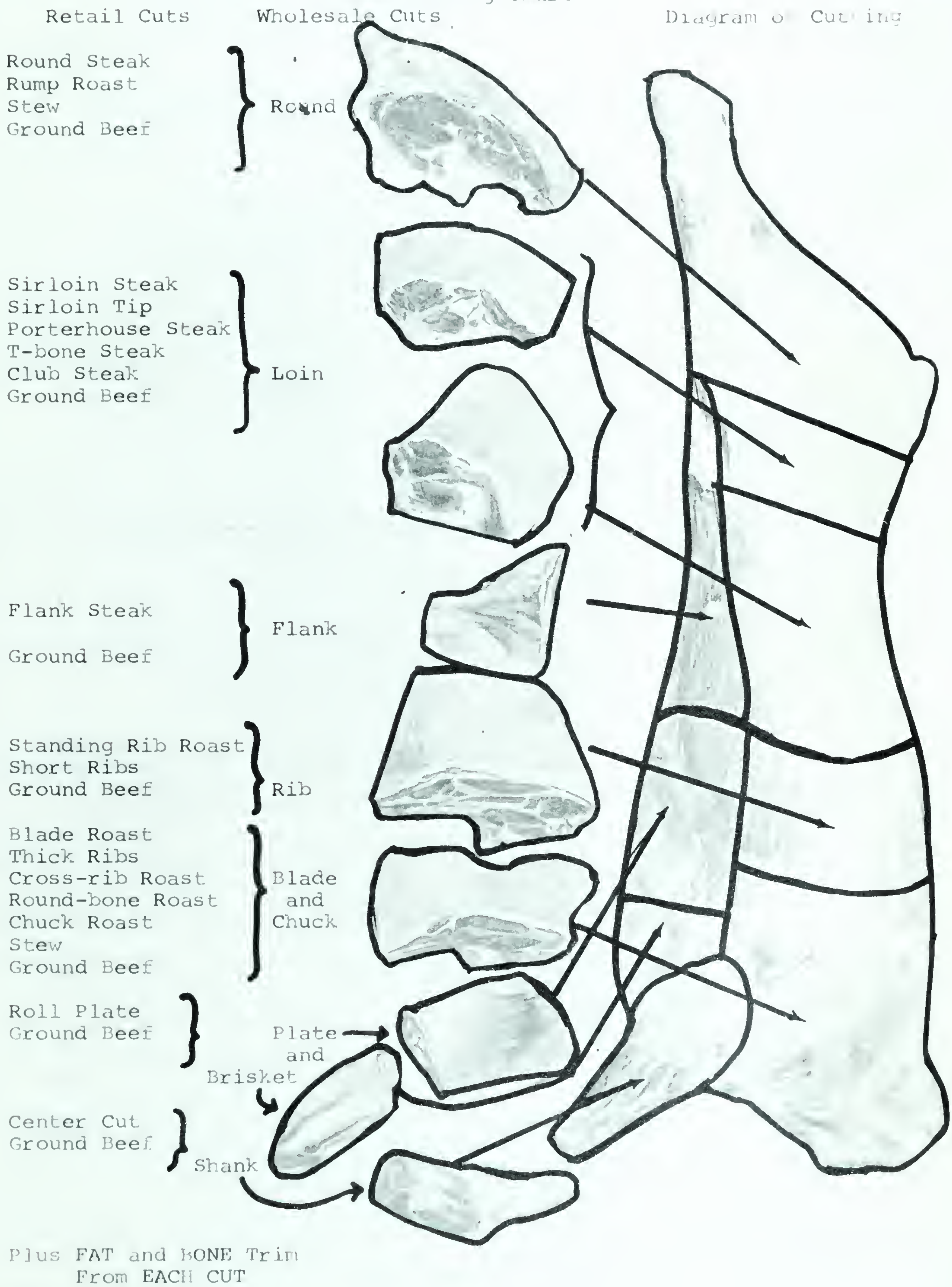
The cutting procedure was that outlined in the Safeway Beef Manual (1960) with the following modifications. The carcass was divided into wholesale cuts as shown in Figure 3. The forequarter was removed between the 11th and 12th ribs by a cut adjacent to the 11th rib along its full length. The flank was removed adjacent to the stifle and included about six inches of the 12th and 13th ribs at a point coincident with the plate cut. The loin was cut on a line anterior to the pelvic bone, just anterior to the <u>trochanter major</u> of the <u>femur</u> crossing the fourth sacral vertebra and included a small portion of the <u>femur</u>. The undercut flared a little toward the round to be parallel to the 12th rib cut. The sirloin tip was removed from the bottom loin adjacent to the stifle joint and pelvic arch. The rump and hip which remained were included as one wholesale cut in this study and designated wholesale round.

The shank was removed just above the bony rise (<u>lateral condyle</u> of the <u>humerus</u>) in the middle of the arm on a line parallel to the brisket. The plate and brisket were cut off on a line joining the shank cut with a point on the 11th rib about two-thirds of the distance down the rib.

The prime rib was removed for a five-bone rib between the sixth and seventh ribs by a cut adjacent to the sixth rib. The chine bone and spinal

Appendix 8

Figure 3
Beef Cutting Chart



processes were left on the wholesale rib-cut. The blade consisted of the next two or three anterior ribs. The blade is reported with the chuck because of the variation in blade cuts. The chuck which remained is referred to as a square cut chuck.

The wholesale cuts were defatted, trimmed and partially or completely boned to reflect retail style trim as outlined in the Safeway Beef Manual (1960) with the following modifications. Surface fat was trimmed to within ½ inch on the thick cuts and to within ¼ inch on the thinner cuts such as brisket. Vertebrae were removed from posterior sirloin steaks and the chine bone removed from rib and loin.

Each wholesale cut was weighed and then the constituent retail cuts weighed separately as were the fat plus the bone trimmed from each wholesale cut. Retail bone-in cutability refers to the total percentage of salable meat from a side. Trim consists of the sum of fat and bone trimmed from the side as a percentage of the side.

Appendix C - Laboratory Procedures

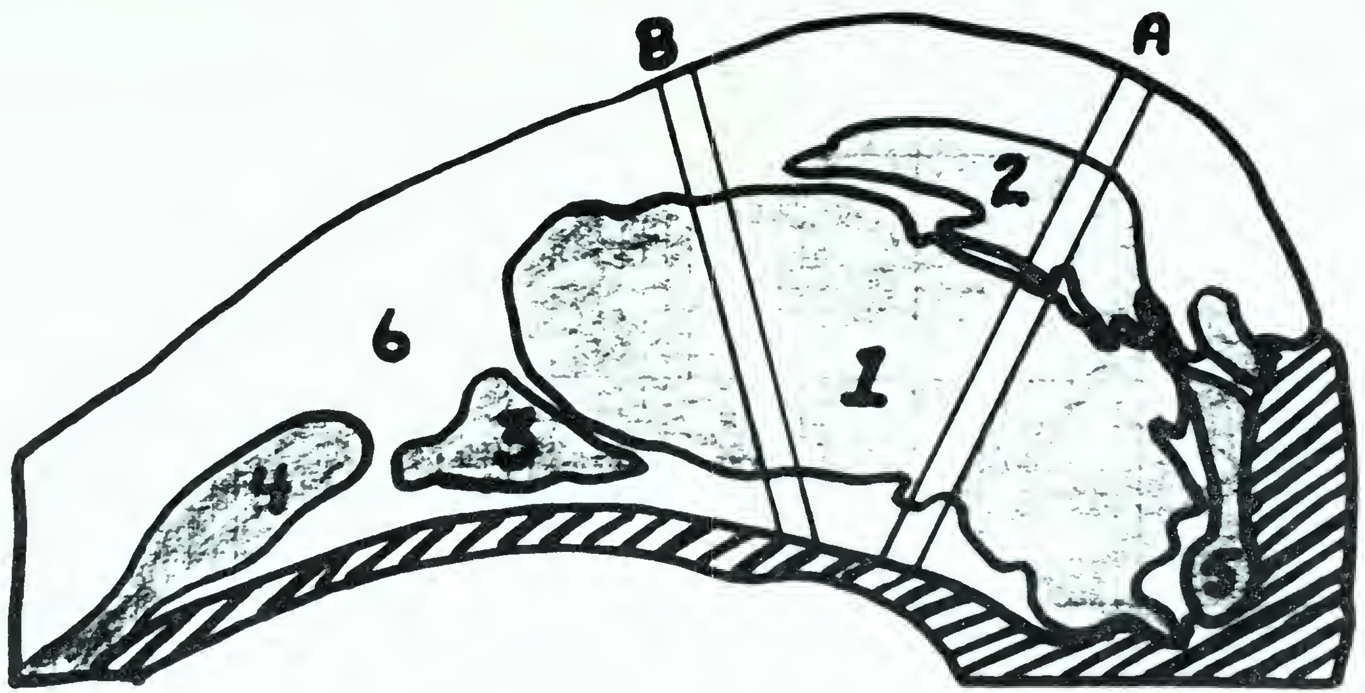
1. Probe sampling of _longissimus dorsi_ muscle

A coring device 0.25 inches in diameter and 15 inches long patterned after that of Kennick and England (1960) was used to take a pair of probe samples from between the 10th and 11th ribs. One of the pair was taken through the widest portion of the combined _longissimus dorsi_ and _spinalis dorsi_ muscles, Figure 4, one was taken from a position about three quarters of the way along the length of the muscle (Harwin _et al._, 1962). The locations of these probes were chosen in an endeavor to sample the muscular tissues, the external fat and the intra-muscular fatty tissues after Kennick and England (1960). The fatty tissues were easily and uniformly cut by the coring device, but the lean tissues required care in sampling and use of a serrated cutting edge. A distinct cut was obtained by a slow rotating thrust. Harwin _et al._ (1962) found no significant difference between fat content of probes between sides but a

Figure 4

Cross Sectional Tracing of Rib Cut
Taken Between the 11th and 12th Ribs
Showing the Locations of the Probes A and B

Probes Taken at A and B



Muscles:

1 Longissimus dorsi (rib-eye)
2 Spinalis dorsi
3 Longissimus costarum
4 Latissimus dorsi
5 Multifidus (superior) dorsi
Fat
6 External or Subcutaneous Fat Cover

signiticant difference was noted between locations of probes on one side. Caution was used in coring to standardize the location for repeatability.

The core samples were taken on the day following slaughter and placed in sealed sample bottles and held under refrigeration until physical separation. The core samples were removed from refrigeration and physically separated into fat and lean tissues after Aunan and Winters (1952) and weighed on an analytical balance. The percentages and weights of fat and lean tissues were determined for each individual probe and reported as averages for the pair. The muscle tissue was then frozen in sealed sample bottles for ether extract analysis and histological study at a later date.

2. Ether extract analysis for intramuscular fat content

The procedure used for ether extract analysis for the intramuscular fat content of the muscle was a modification of the official A.O.A.C. (1955) procedure as modified by Bowland (1963). The Goldfisch extraction apparatus which utilized an aluminum extraction thimble was used.

Care was taken to remove all bone chips and to avoid excessive delay in procedure to minimize moisture loss. A sample of approximately 4 grams from the core was spread out in a thin layer on a No. 1-12 cm. filter paper and dried in an oven for 6 hours at 100°C. The dried sample was then scraped from the filter paper and ground with washed sand. The dried, ground sample was then spread out in a thin layer over the same filter paper and transferred to a tared extraction thimble, which was placed in a glass open-end sample container. Thirty ml of anhydrous ether was transferred to a tared beaker and placed on the Goldfisch extraction apparatus. A four hour extraction period followed. The beaker was then removed from the extraction apparatus and dried for 1 hour in an oven at 100°C, cooled in a desiccator and weighed. The weight of the ether extract as a percentage of the total weight of the sample is designated per cent ether extract.

3. Mechanical evaluation of longissimus dorsi muscle tenderness

The tenderness evaluation procedure was a modification of the method used by Burrill et al. (1962) with the L.E.E. - Kramer shear press. Laboratory of Electronic Engineering, Washington D.C.

The basic unit consists of a hydraulic drive system for moving a piston at any predetermined rate of travel between 15 and 100 seconds per full stroke. Measurement of force is provided by the compression of a proving ring dynamometer. Fixed point resolution of 0.5 per cent may be obtained from individual calibration curves. An electric transducer connected to a recorder gives a time - force curve for the entire stroke. The standard test cell consists of 10 parallel stainless steel blades 0.124 inches wide which precisely mesh with the 0.126 inch slots in the sample box. The blades are the moving part of the cell and are attached directly to the proving ring to eliminate error (Figures 5 and 6).

The complete time - force curve was used to measure shear force. The distance from beginning of ascent of the curve to the end of the stroke is a measure of sample size. The slope of the leading edge of the curve is a measure of sample firmness or yielding quality (Kramer, 1961). A gradual rise indicates the compression of a soft centered sample; a group of fibers gives a sharp peak. Reported shear values are maximum pounds of shear force per gram of sample for a stroke time - distance of 3½ inches per minute.

The first porterhouse steak from the left side of each carcass was removed after at least 12 days and not more than 17 days aging at 35-40^{o}F. The steak was removed and frozen during regular cutout for the fed-yearlings. The frozen steak was wrapped in freezer wrap and stored until January, 1963; at which time a 1-inch diameter core was taken from the lateral end of the frozen longissimus dorsi muscle with a tungsten-steel coring-tube driven by

Figure 5

L.E.E.-Kramer shear cell and core samples of meat ready to be sheared for tenderness evaluation

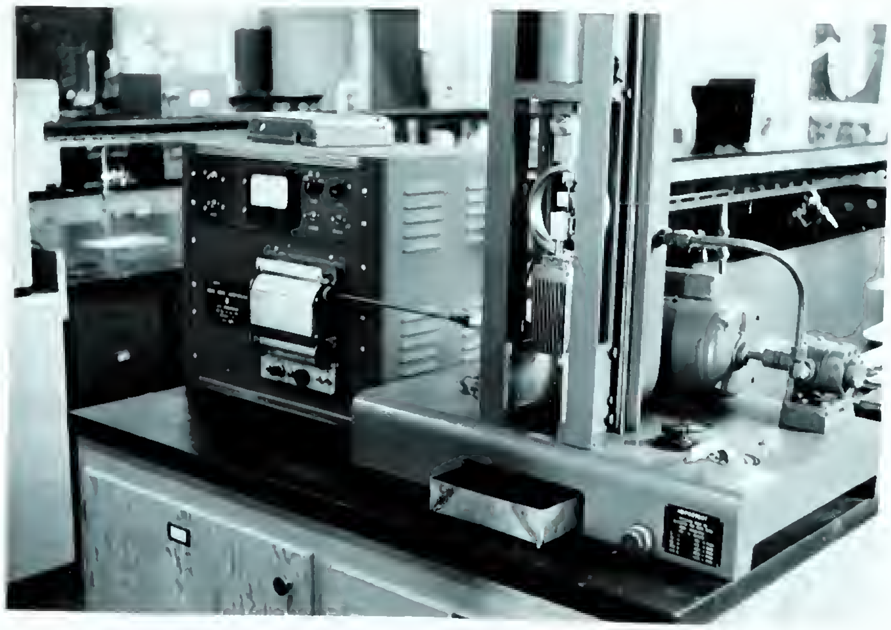


Figure 6

L.E.E.-Kramer shear press and Recorder: the shear cell is placed beneath the shear blades attached to the dynamometer

a ½ inch electric drill. The frozen core was stored in a coded polyethylene bag until it could be sheared. In the fed-calves the 1-inch core was removed from the longissimus dorsi muscle of the first porterhouse steak during retail cutout. The core was then frozen and stored in a coded polyethylene bag until it could be sheared.

A lateral location was chosen after preliminary studies showed it to be the most repeatable site. Preliminary studies also revealed that fat and collagen deposits invalidated shear values; when necessary the coring site was shifted away from any concentration of fat or collagen.

The frozen core was placed in a 'jig' and divided with the grain of the meat into two samples of approximately equal weight and size; 1¼ inches by 1 inch. The samples were then replaced in the sealed polyethylene bag and stored in the freezer until shear evaluation. One of the samples was utilized for a raw shear evaluation and one sample used for cooked shear evaluation.

The sample utilized for the raw shear was removed from the original sealed polyethylene bag and allowed to thaw at 35-40°F for more than 3½ hours in another sealed, coded polyethylene bag. Care must be taken to avoid excessive exposure of the sample to air while handling the samples. The shear force value variation due to evaporation and firmness was standardized by removing the sample from the sealed polyethylene bag and placing it on a tray at room temperature for not less than 5 minutes or more than 8 minutes -- if less time was allowdd the sample was too firm and if more was allowed juice was lost and the sample became soft and flexible. The sample was placed in the L.E.E. - Kramer shear cell so that the cutting bars were perpendicular to the grain of the meat and a minimum of three slots in the cell were covered by the sample. The shear was run at speed 4 with a 500 pound ring and 200 pound setting on the recorder.

4. Cooking procedure

The remaining frozen sample from a core was thawed in the previous manner from the polyethylene bag and was deep fried in lard (Paul *et al.*, 1952) to obtain standard conditions of temperature and cooking time. Thermocouples were assembled in such a manner on a multi-recorder that two thermocouples recorded the fat temperature, two thermocouples were embedded in the meat sample and two thermocouples recorded the air temperature in the room (Figure 7).

After thawing for 3 hours at 35 - 40^{o}F in the sealed polyethylene bag the sample was removed from the polyethylene bag and placed on a tray. A thermocouple was inserted into each end of the sample. The sample was then lowered into fat which was held at 147^{o}C (294^{o}F) in a General Electric Deep Fryer. When the internal temperature of the meat sample reached 63^{o}C (145^{o}F). the equivalent to medium well done, the sample was removed from the fat. After removal from the cooking fat the sample was placed on a tray to drain and cool at 35^{o}F for at least 3 hours. The cooked sample was then sheared in a similar manner to the raw sample.

Cooked samples were considerably tougher than raw samples necessitating a 500 pound ring and a 300 pound recorder setting.

5. Histological examination

A sample of approximately 2 grams from the separable lean removed by a probe in the packing plant was fixed in 35 per cent formalin for 36 to 48 days before histological examination. The fixed sections were removed from the formalin and a slice 1/64 of an inch long was immediately cut with a sectioning knife, perpendicular to the grain of the meat. The slice was immediately transferred to a drop of water on a glass slide to prevent excess dehydration. This small slice was teased apart with a probe under a magnifying glass until the drop of water became slightly cloudy; a cover slip was applied

Appendix 16

Figure 7

Apparatus used to cook meat samples showing the multi-recorder, thermocouples, General Electric Deep Fryer and sample tray

in such a way as to preclude air bubbles and the slide examined under a microscope. If satisfactory muscle fiber separation had taken place the slide was then numbered (Figure 8).

A Model V.H. No. 42-63-05-61 Bausch and Lomb micro-projector which was developed for wool fiber measurement was used for magnification. The slide was inserted in the mechanical stage of the projector with the cover glass towards the objective. The projected image was focused onto a sheet of white paper with a scribed circle 10 cm in diameter in its center. The mechanical stage was used to bring the fiber image into this circle where it was measured. The projector was pre-set to a magnification of 500X. Measurements were made with a metric scale graduated in mm with each graduation being equal to 2 microns at this magnification.(Figure 9).

The whole slide was first scanned quickly to obtain an indication of the distribution patterns of the muscle fibers. If insufficient separation or too few separate muscle fibers were observed the slide was discarded. In an attempt to reduce sampling error individual fiber measurements were not concentrated in any one area of the slide. Actual measurement of muscle fibers began in one corner of a slide and the field was scanned from there by moving the slide. Muscle fibers were measured only if they were in the prescribed circle on the projection table, distinct separate fibers and at least 50 microns long. At least 100 individual muscle fibers were measured in each slide as Joubert (1956) concluded this number of measurements was needed for reasonably accurate results from one muscle. Data were obtained for the mean and standard deviation for each sample examined.

Appendix 18

Figure 8

Equipment used in preparation of microscopic slide for histological measurement of muscle fiber diameters

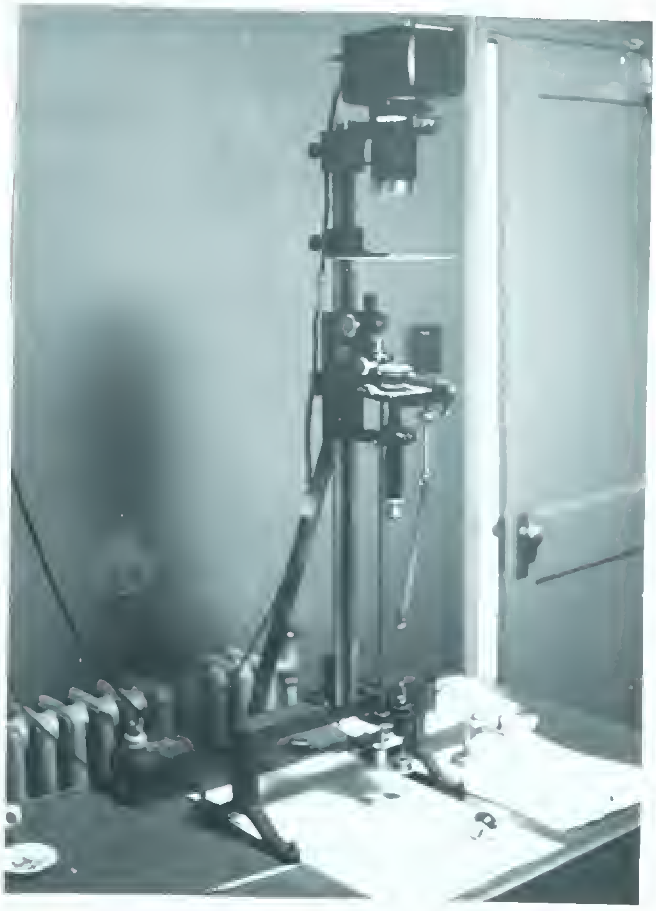


Figure 9

Model V.H. No. 42-63-05-61 Bausch and Lomb microprojector used for projection of muscle fiber images